IBA TECHNICAL REVIEW

15

Microelectronics in Broadcast Engineering

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IBA INDEPENDENT BROADCASTING AUTHORITY

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15 Microelectronics in Broadcast Engineering

Contents

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Introduction

by Baron Sewter
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The microelectronic revolution has been with us for the past quarter of a century. During that period most branches of engineering have experienced an avalanche of new technology, made possible by new and highly miniaturised electronic components. This unprecedented scale of change continues, and at ever-increasing pace which is now further accelerated by the convergence of computer and communication technologies.

The first integrated-circuit (ic) was developed in the USA as long ago as 1958; but there is general acknowledgement that the idea had been conceived several years earlier in Britain, at the Royal Radar and Signals Establishment. By the mid-sixties the era of low-cost digital ic devices had begun and designers were beginning to look forward to large scale integration and the very low power requirement of complementary metal-oxide semiconductors. Much before the seventies, the long struggle for increasing the switching frequency of ic's while retaining low power dissipation was proving successful, as were other researches in micro-computing devices. By the early seventies the whole structure of the electronics industry had been profoundly affected.

At first the so-called 'silicon chip' made but little impact on the thought of radio and television broadcast engineers; but, at about that time, Research and Development engineers were eagerly recognising the significance of 'digital techniques', even though many of their colleagues worldwide were still striving to produce high quality analogue colour systems on numerous television networks.

Two of the early trail-blazers in the application of ic's to professional broadcast equipments were the line and field rate standards converters, developed in 1971 and 1972 respectively, by the IBA. These equipments showed that improved performance and operational facilities could be achieved by using digital ic techniques. Gradually, it became evident that ic's could revolutionise most designs of broadcast television and radio equipments, and could contribute towards the realisation of new services, such as teletext. Indeed, today, practically every item of equipment in the broadcasting chain—from video and audio origination to domestic receivers—is benefiting from conversion to ic mode.

While engineers in the field of applied research, development, and design were taking advantage of ic's, semiconductor manufacturers in many countries were working hard to increase the reliability, capability, complexity and yield of these devices. The great advance from the low-power thermionic valve to the germanium transistor, and thence to the silicon transistor, was followed by the advent of the silicon ic and by the impassioned race towards development of small, medium, large and very large scale ic's. These latter four stages of development have vastly increased the number of active elements which can be incorporated within a single 'chip' measuring only a few square millimetres in area. From initial content of less than ten active elements, the number now achievable exceeds 100 000, and this capability has enabled manufacturers to provide, for application engineers, complete subsystems and microprocessors on single lsi or vlsi devices. Yet, still the pace increases; and, today ultimate production of a vlsi containing even a million active elements seems more than a pipe (or pipeline) dream.

However, we must be careful to avoid imagining that the microelectronics of today represent 'the end of the road', or even the second signpost pointing towards that end. Integration is not necessarily the answer to all electronic problems. Integration of inductors will still remain difficult even if the gyrator (active filter) can be suitably adapted. We imagine that the semiconductor is ageless; yet, we know that it can easily be killed; and microelectronic operational faults, though seldom arising, can be difficult and

costly to diagnose and rectify. Also, development of linear devices still lags behind that of digital devices; and full advantage has yet to be taken of bipolar technology and of devices such as the cadmium metal-oxide semiconductor (cmos) and of the vertical-groove metal-oxide semiconductor (vmos).

Within the field of microelectronics, British engineers have achieved many successes in specialist areas, and IBA engineers have contributed much towards the integrating of microelectronics into the operational broadcast environment. Nevertheless, we in the UK are fully aware that much remains to be done in the 1980s, and that further researches will be in high demand thereafter. Therefore, the new Inmos operation, having evaluated the rapid progress achieved in microelectronics, is now preparing to contribute towards accelerating that rate of progress.

This volume, which describes some of the equipment emanating from the IBA Experimental & Development Laboratories at Crawley Court, reveals some of the problems, and a few of the rewards, of the silicon microelectronic revolution.

GEORGE McKENZIE, BSc, CEng, FIERE, joined the IBA in 1968 to become Head of the newly-created Automation and Control Section. He previously spent ten years in industry working on numerous projects connected with automation and computer techniques. His career has also included ten years in the BBC Designs Department. He is married, has two children, and lives in Hampshire.

Microprocessors in Broadcasting

by G A McKenzie

Synopsis
The author describes the evolution of microprocessors into the broadcasting arena. He suggests that the use of microprocessors will not ease the work of engineers; but that, with the new techniques now available, expectations of equipment performance and system performance have risen.

Ten years ago the idea that computers might have a place in broadcasting engineering operational control rooms seemed fanciful to most in the broadcasting industry. As was well known, computers represented large capital outlay, occupied large quantities of space, were costly of electricity, paper, maintenance and labour, and needed replacement every few years. In consequence, well-respected engineers are on record as having stated that computers would enter broadcasting control rooms 'over their dead bodies'.

Many engineers at that time had vague ideas of electronic computers as consisting of electronic logic circuits which, when connected in certain ways, could be made to assist in the solution of certain problems. Further, they understood that this was because computers could repeat, usually quite accurately, complex sequences of electronic signals. The result would be to produce output information related to the input data; but, in each separate case, the particular sequences required for this had to be defined by human intervention. Such computers had been available in mechanical form for many years, at least since Hollerith's processor of 1890, but the new development was to arrange that a fixed conglomerate of electronic hardware could support a range of different sequences, or programs of sequences. This was effected, not by banks of mechanically operated switches, but by electronic switches which instantaneously influenced the pattern of control signals. An algebra to represent the positions of the switches provided the link with the ingenuity of the engineer. In this manner programs of sequences of signals were represented by written coded information. The production of such information had become known as 'programming'.

At that stage the engineers seemed to lose interest; and a new vocation, that of the computer programmer, was born. The programmers used the rule books which the engineers had written to suit the particular hardware, and their job was made more efficient by further developments of the 'algebra' used. These so-called 'programming languages' developed so that whole sets of sequences, each previously represented by a series of separate codes written in 'machine language', were each given single codes.

The computer itself was then brought into use to generate its own machine code from the 'higher level' statements.

So far as the IBA Engineering Division was concerned, the picture began to change in 1968. In its Automation and Control Section, IBA engineers then began experimenting with the use of computers in broadcast engineering control, and some of the results of that early work were reported in Volume 1 of this *IBA Technical Review* series. At that time a steady reduction in the cost of computer hardware components was anticipated. This tendency was dramatically accelerated when, in 1971, the Section

became one of the first groups in the United Kingdom to begin experiments with new electronics devices called 'microprocessors'. These devices took the engineer straight back to the early 1950s and involved him again in writing machine code for very primitive computer configurations. However, microprocessors were so small and cheap as to present a completely new range of possibilities in electronic design. It was possible to look forward to more efficient hardware production with a range of different applications, previously requiring a range of different equipments, to be served by one hardware configuration with appropriate computer programs.

Since 1971, development has been very rapid and the simple 4-bit microprocessors of that year have, within less than ten years, given place to powerful 16-bit machines.

Perhaps one of the most important effects of this revolution has been the enforced closure of the gap between hardware and software specialists.

There is a need for a type of engineer competent in both fields. In fact, in 1981, the competent engineer must be able to choose system solutions providing the correct balance between hardware and software processing techniques. Unless the balance is judged correctly the adverse effects on performance and cost of equipment can be profound. The use of the microprocessor is not a new technique to replace others, but an extra one to be used with the more traditional analogue and digital hardware techniques. No one such technique is 'out of date'.

The microprocessor will not replace the professional engineers, nor even make their work easier. Equipment and system performance expectations have risen with the availability of the new techniques. In responding to these expectations engineers are able to work more effectively, making the most of the contributions from their desks. Their ideas are expressed through the ingenuity of the software they design as well as in more traditional ways.

During the past ten years equipment for electronic computing has become very much cheaper, cooler, quieter, smaller and lighter. The following table indicates the main features of equipments in use in the IBA Engineering Division during that period, and summarises the progress.

PROGRESS IN SMALL COMPUTER HARDWARE IN THE TWELVE YEARS 1968–1980

	1968 'MIDI' COMPUTER CONFIGURATION	1980 MICRO COMPUTER CONFIGURATION
Word Length	16 Bits	16 Bits
Memory Type	Ferrite Core	Electronic—RAM ROM & E PROM
Memory Size	4k Expanding to 32k	4k Expandable to 500k
Memory Cycle Time	1 μs	1 μs
Speed: Add	2 μs	0.6 μs
Subtract	2 μs	0.6 μs
Multiply (hardware option)	5 μs	<1 μs
Divide (hardware option)	10 μs	<1 μs
Input/Output Modes	DMA Option	DMA Option
Instruction Complement	70 Instructions	100 Instruction Groups
Control Panel	Control (key & lamp) Console	24 Keys & 8-digit LED Display on Board
Approx. Dimensions (less console)	24″ × 24″ × 36″	12″ × 12″ × 12″
Approx. weight (excluding power pack)	60 kg	0·7 kg
Approx. Total Cost configured as above (adjusted to 1980 prices)	£60 000	£700

PATRICK CROZIER-COLE, MA (Oxon), joined the Authority in 1967 as a transmitter engineer. In 1970 he was appointed Head of the newly formed Telemetry and Automation Section. The work of the Section involves many aspects of automatic monitoring and control systems for the IBA's transmitting stations and Regional Operations Centres, and the extensive application of microprocessors. Previously he worked with the Marconi Company on the development of high power UHF transmitters for colour television. He and his wife and four children live in Wiltshire.

Regional Operations Centres — The Next Generation

by P A Crozier-Cole

Synopsis

The author reviews the reasons for setting-up the first of four Regional Operations Centres at Croydon. He describes the telemetry systems, the operator/telemetry interface and the comprehensive visual display unit used for transmitter fault diagnosis. The Croydon ROC was the prototype for ROCs now being installed at St Hilary, Emley Moor and Black Hill.

The Regional Operations Centres (ROCs) which are currently being designed for Emley Moor, St Hilary and Black Hill will, in several respects, differ from the prototype at Croydon. This article explains these differences and the reasons for them. The three major factors are as follows:

First, the basic design and operational philosophy of the Programme Injection Points (PIPs) are unchanged although only one set of automatic monitoring equipment will be provided and with minor changes in mechanical layout.

Secondly, the current ROCs are now being designed to cater for two complete television networks and, therefore, also for multi-operator activity depending on the various loads of normal traffic at different times of day.

Thirdly, the functions performed at Croydon by the rebuilt GEC Teledac and E & D Department Video Display Unit (VDU) System are to be transferred to a Ferranti Argus 700 mini-computer system.

There will be no change to the three major functions of the ROC. These are:

1. Control
2. Supervision
3. Communication

These three functions can now be reviewed in the light of the factors outlined above.

1. Control

Control can be subdivided in turn into:

a Daily routine controls of PIPs
b Urgent controls of PIPs
c Occasional remote controls of outstations.

At Croydon, routine controls are set up on the wall-mounted Time Scheduling Panel (TSP); but, on the new system, it has been decided that this can be done equally well at the desk, and by use of appropriately laid out VDU pages and keyboard actions. The preset times will always be visible to the operators on the Annunciator Panels above the picture monitors; but, as an additional safeguard, the Argus mini-computer system will prompt the operator to check these times each day.

Urgent controls to PIPs are very seldom required; but, when they are needed, speed is essential. The Transmission Control Panel (TCP) on the desk is therefore retained, but with altered layout.

At Croydon, the other remote controls are applied from wall mounted Teledac key and lamp panels. This might seem anomalous since all other operations can be performed at the desk. The original mimic diagrams appearing on the VDU were laid out with an area reserved for remote control designations on each page, as appropriate. It then becomes a simple matter to select and actuate the remote controls from the keyboard, and the wall panels are no longer needed.

2. Supervision

Supervision can be subdivided into:

a Company Monitoring

b Transmitter Network Monitoring.

Company monitoring is still to be achieved by off-air monitoring of the radiated pictures. It cannot be excluded that the number of sources to be monitored may be doubled by the advent of the Fourth Channel, so the monitor suite has been re-designed to accommodate a maximum of two rows of five monitors. The Annunciator Panels above each are retained.

The Station Status Panel (SSP) is retained, to provide a continuous up-to-date overview of the network and also to give fast access to the VDU displays of each station. Space is reserved for a second SSP for the second network, because accounting of differences in programme paths and dependencies (and, hence, of priorities) might be necessary.

Transmitter Network monitoring is still to be done by ordinary telemetry and automatic monitoring equipment designed for quantifying insertion test signal (ITS) distortions. Numerical telemetry as demonstrated at Croydon in January 1980 is also being provided. Much is currently being learned from operational experience; but, in order to avoid restriction of future operational requirements, various options are being provided which can readily be adopted or abandoned, as experience dictates. These include automatic on-site executive control at the outstation, manual interrogation of all parameters on demand, automatic interrogation of the status of the station output to a maximum of three times per day, rapid automatic interrogation of certain parameters along a chain of stations, and automatic logging and display of results. These facilities are logical extensions in the application of numerical telemetry beyond the very fundamental system demonstrated at Croydon.

The Ferranti equipment is designed to combine the functions of telemetry master and the VDU/Keyboard system, and will use two Argus 700 processors, supplemented by duplicated disc stores. The reasons for choosing such equipment are:

a The need to cater for data from two TV networks, which exceeds the practical limit of Teledac capacity.

b The need to install a system capable of further systematic and well documented expansion and development.

Two VDUs and keyboards are being provided, to permit independent action by more than one operator.

3. Communication

The last major ROC function is the re-distribution of all the incoming information to those who may need it, e.g. to:

a Mobile Maintenance Teams (MMTs)

b Programme Companies and PO Switching Centres

c Crawley Court.

One lesson learned from Croydon was that the ergonomics of the desk would be much improved by bringing the Communications Panel much closer to the VDU since the operator would often be working simultaneously with both. In the new desk design this has been achieved and an adequate area in front of the operator, for purposes of writing, has been preserved.

It is also possible to improve other aspects of communication by exploiting the Ferranti equipment. One option is for the running log of the ROC to be kept as data and either printed-out on site or transmitted to Crawley Court, thus to replace existing forms which are completed manually. Options also exist for the automatic passing of printed information to MMTs, either directly or on demand via the public telephone network. Again, the need and value of these options will be determined from experience.

Finally, it is intended that the prototype installation at Croydon shall be replaced by a Ferranti system comparable to those being installed at the other three ROCs at the end of the current phase of this project.

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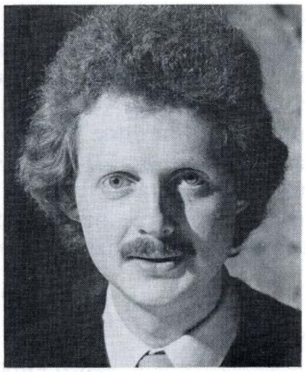
PETER BARNETT, BSc, ACGI, joined the IBA's E & D Department in 1976 from Imperial College, London, as a Junior Engineer. There he worked on the IBA Test Patterns, Digital and Audio Companding, and Digital Audio for Video Tape Recorders. He transferred last August to the Transmitter Project Section where he is currently engaged on local radio projects.



The Electronic Test Pattern Generator

by P R M Barnett

Synopsis

The electronic test pattern generator has been developed to replace slide scanners which produce Test Card F at programme injection points in the Independent Television network. It is a compact and reliable unit, requiring virtually no maintenance, and uses digital techniques to generate the signal from data held in read-only memories.

The test pattern has many features designed to aid the setting up of colour and monochrome receivers, and is transmitted daily before commencement of programmes.

INTRODUCTION

Until recently, one of the test signals transmitted daily before commencement of IBA television programmes has been the familiar Test Card F. The test card signal is produced by a slide scanner, which is a large and expensive piece of equipment requiring regular maintenance and adjustment to remain within the specified limits of performance.

The need of an electronically generated test pattern has arisen through the trend towards unattended operation of transmitting stations and the introduction of the IBA Regional Operations Centres. The test pattern is generated digitally, and is inherently stable, requiring virtually no maintenance. It is, therefore, ideally suited to long periods of unattended operation.

TEST PATTERN

The test pattern has many features designed to aid receiver alignment and picture quality assessment. These include:

1. Crosshatch pattern

This serves for checking of static and dynamic convergence.

2. EBU Colour Bars

(75% amplitude, 100% saturation). These serve for checking the operation of the colour decoder.

3. Multiburst

This consists of six blocks of vertical bars representing horizontal frequencies of 1·5 MHz, 2·5 MHz, 3·5 MHz, 4·0 MHz, 4·5 MHz and 5·25 MHz. These serve for checking of receiver frequency response and ability to resolve fine detail.

4. Greyscale

This provides luminance increases of equal amount as a check on the amplitude linearity of receivers. The luminance levels are 0%, 20%, 40%, 60%, 80% and 100%.

5. White needle pulse on black background

Any significant reflections of the signal from large buildings or hills can be detected as a displaced image of the needle pulse within the black rectangle.

6. Black rectangle between white rectangles

This serves for the making of low frequency response tests. Poor low frequency response will cause lack of uniformity of luminance level across the rectangles, the right-hand ends tending to be grey rather than black or white.

7. Red rectangle between yellow rectangles

These are located above the needle pulse and serve for checking of chrominance-luminance delay. Any such delay causes displacement of the colours within these rectangles.

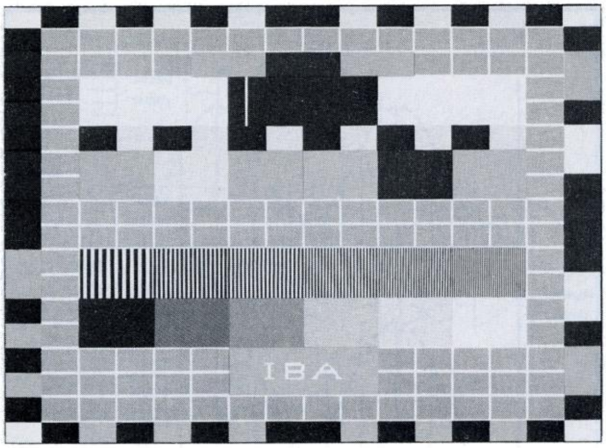


Fig. 1. The Test Pattern.

8. Castellations

Besides indicating the edge of the picture, these serve for testing the operation of the receiver sync separator. The castellations are positioned such as to assist identification of the source of any disturbance.

TEST PATTERN GENERATOR

The test pattern generator consists of three circuit boards, one for each of the functions shown in Fig. 2. The equipment is synchronised by line drive, field drive and mixed blanking, from an external sync pulse generator, and provides R, G and B signals which are fed to the station colour encoder.

Pattern Generator Board

A 15 MHz oscillator, phase-locked to 960 × line frequency, is used to clock picture component information out of read-only memory (ROM). As shown in Fig. 3, part of the divider chain in the phase-locked loop is used as the horizontal address counter for the ROM. The vertical address is obtained from a separate counter which is clocked by line drive; and, in order to maintain synchronism, is cleared by field drive.

Information in odd and even fields is identical, so no distinction between them is made. The picture itself is reduced to eighteen rows of sixteen blocks; and, in general, the content of each block is encoded and stored in one byte location in the ROM. The exceptions are the crosshatch verticals, and those blocks which contain detail, e.g., the needle pulse, the multiburst and the IBA logo.

The blocks containing the needle pulse are allocated the code for black, but with one extra bit set. A narrow pulse is generated by logically combining some of the least significant horizontal address bits, and this pulse is gated with the extra bit in the code for black, so ensuring that the needle pulse occurs only where it is required, rather than over the whole height of the picture.

The crosshatch verticals are generated in a similar manner. Again, pulses of suitable width and timing are generated by logically combining some of the least significant horizontal address bits, and these are gated by a bit from the ROM especially allocated to this task.

The IBA logo is held in a separate ROM but which is also addressed by the vertical and horizontal

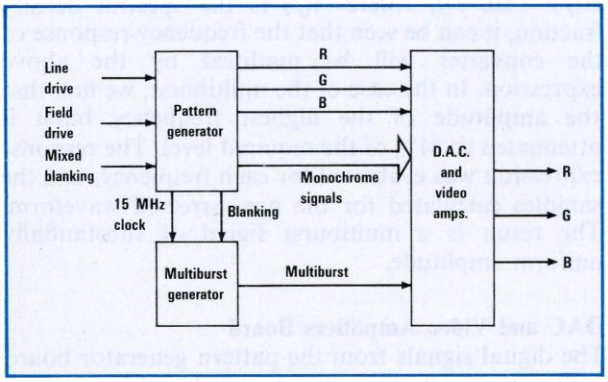


Fig. 2. Test Pattern Generator—Block Diagram.

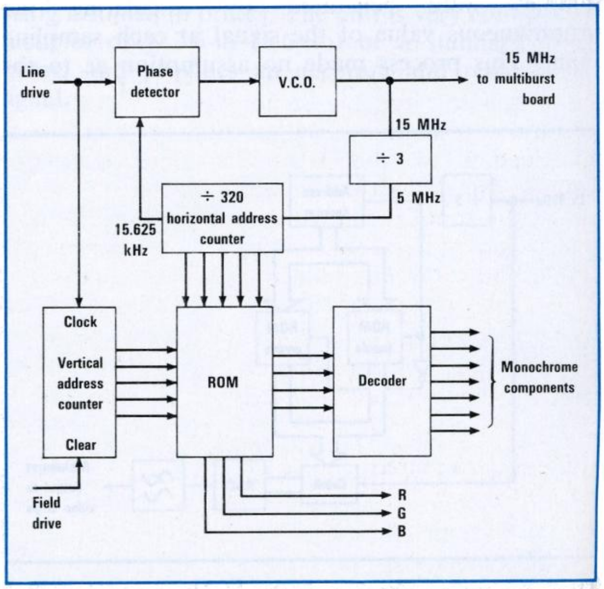


Fig. 3. Line-locked counters address the ROM to produce R, G and B signals and encoded monochrome components.

address counters. The output of the ROM is in the form of 8-bit words, and a shift register converts these to a serial bit stream. Once again, this is gated with a bit obtained from the master pattern ROM, ensuring that the logo appears only where required.

The multiburst is generated in a quite different manner, which is described below. However, as in the other cases, the ROM generates a signal which is used to enable or disable the multiburst.

Multiburst Generator Board

The signal produced by the multiburst generator board is stored in further ROMs; but, unlike the pattern generator board, the outputs of which are digital, the multiburst generator board produces an analogue output.

PCM samples are stored in two ROMs (see Fig. 4) which are multiplexed to achieve a data rate of 15M samples per second. Originally, the samples were calculated to a resolution of eight bits, but only the six most significant are used by the digital-to-analogue converter (DAC). It was found that the increase in quantizing noise caused by reducing the resolution to six bits produced an almost unnoticeable degradation of the picture, any contouring being disguised by the large amount of high frequency content of the picture. This enabled considerable simplification of the design of the digital-to-analogue converter (DAC), and permitted the use of components of standard values and of 1% tolerance. The multiburst waveform samples were generated by calculating the instantaneous value of the signal at each sampling point. This process made no assumption as to the

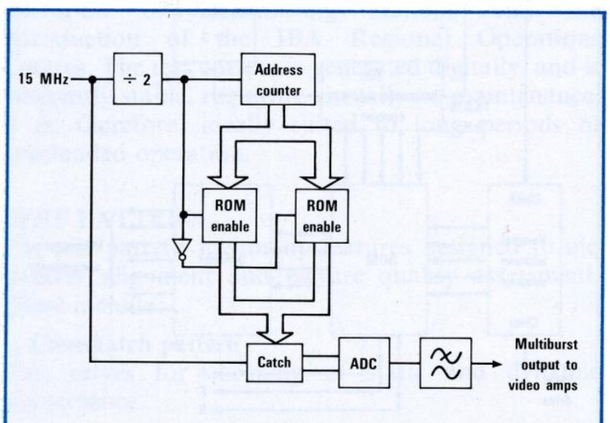
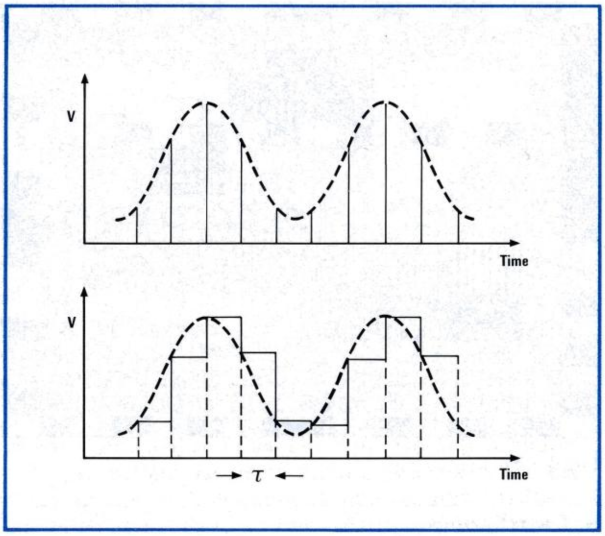


Fig. 4. Multiburst Generator. The two ROMs, containing samples of the multiburst waveform, are multiplexed to give a data rate of 15M samples per second.



Figs. 5a and 5b: *Top:* Theoretical sampled waveform; *Bottom:* The reconstituted signal before filtering.

values the signal may take between sampling points, other than those imposed by limiting the bandwidth of the signal to less than half the sampling frequency.

The signal is reconstituted from the samples by latching the digital values at the input of the DAC, which drives a current proportional to the numerical value of the input. As with its input, the output of the converter remains constant throughout the period of any sample.

The waveform, therefore, differs from the theoretical sampled waveform in that the former consists of a train of pulses of width, and the latter of infinitely short impulses.

Since the spectrum of an impulse is flat, and that of a pulse of width is given by the familiar expression $A(f) = \sin f/f$, where $A(f)$ is the spectral density fraction, it can be seen that the frequency response of the converter will be modified by the above expression. In the case of the multiburst, we find that the amplitude of the highest frequency burst is attenuated to 81% of the required level. The response expression was evaluated for each frequency, and the samples calculated for the pre-corrected waveform. The result is a multiburst signal of substantially uniform amplitude.

DAC and Video Amplifiers Board

The digital signals from the pattern generator board control the state of the current switches shown in Fig. 6. The amount of current supplied by each switch is

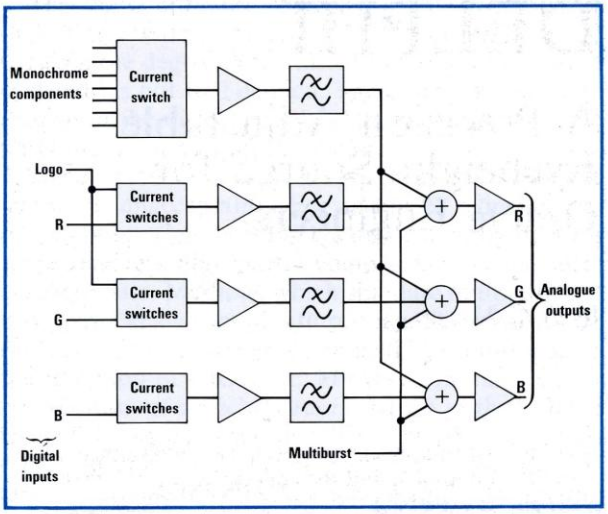


Fig. 6. DAC and Video Amplifiers Board. Digital picture component inputs control current switches which drive the four channels. The monochrome components are then added to the three R, G and B channels.

directly proportional to the amplitude of the signal it is required to generate. For example, the switch operated by the 40% grey signal delivers twice the current of that operated by the 20% grey signal.

The R, G and B colour component signals drive the three separate colour channels; and, since the IBA logo is on a blue background, feeding of the logo signal to the R and G channels results in white letters. All other monochrome components, except the multiburst, are summed in a single monochrome channel and added in equal quantities to the three colour channels. The multiburst is fed directly to the summing points.

Since the current switches are driven by transistor-transistor logic (TTL) signals having rise and fall times of typically a few nanoseconds, the signals contain significant frequency components outside the System I bandwidth of 5·5 MHz. Therefore, the signal in each channel is routed via a low-pass filter to remove those components.

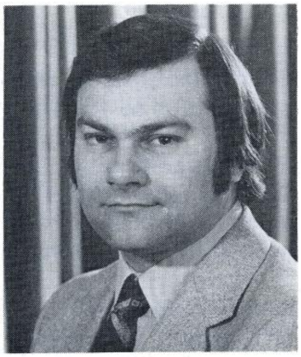
Device Technology

With parts of the circuits operating at frequencies as high as 15 MHz, the obvious choice of logic family is low power Schottky-clamped TTL, and this is used throughout. However, two different types of memory device are used. The ROMs containing the pattern and the IBA logo are ultra-violet (UV) erasable PROMS. These have access times from address to valid data of 450 ns, are relatively inexpensive, and are easily re-programmed should any change of pattern be required. However, this type of ROM is too slow for the multiburst, which requires 7·5 M read operations from each ROM. For this application fusible-link Schottky-clamper TTL ROMs have been used, which typically have access time from address to valid data of only 55 ns.

CONCLUSION

At the time of writing, the test pattern generator is in daily use in certain regions within the UK, and is being installed in others. The unit is very compact. It occupies only 2·6-in (6·6 cm) of a standard 19-in frame, and provides an accurate and reliable test signal.

ARTHUR MASON, BSc, CEng, MIEE, joined the IBA Automation and Control Section in 1973, having graduated from City University, London. He has since transferred to the Video and Colour Section and is at present working on various projects in the video field.



DELPHI

A Precision Adjustable Eyeheight Source for Oracle Engineers

by A G Mason

Synopsis
The author describes a decoder test equipment and laboratory eyeheight standard called 'Delphi'. The function of the equipment, a combined video and teletext test source, is described and decoder testing methods are given in a set of application notes. The importance of eyewidth is outlined, and the concept of an 'effective eyeheight' is explained.

INTRODUCTION

One of the most important factors that will determine the success of any broadcast teletext service, so far as concerns the public, is the ability of domestic receivers to decode correctly at low eyeheight values. Although the value of 25% eyeheight, proposed by BREMA, has generally been regarded as an acceptable performance for domestic receivers, many receivers currently available fail to achieve this level of performance. This fact should not be regarded as a reflection upon the teletext manufacturers' ability. The more likely cause is to be found when the methods used for testing commercial teletext designs are examined.

Often the only teletext test signal available to a manufacturer is an off-air signal. Any engineer who has used an off-air signal for test purposes will be aware of the indeterminate nature of off-air waveforms, especially when detailed effects caused by signal distortions are being examined. The problem does not rest there; a manufacturer trying to test his designs has the added problem of trying to reduce the eyeheight of an ill-defined and noisy incoming signal to a value of 25%. He is then faced with the impossible task of trying to find which of the many different types of distortion (all of which are present on his signal and in unknown amounts) are causing his decoder to fail.

DELPHI has been designed to overcome the above problems by generating well-defined video signals containing teletext data, having an accurately calibrated eyeheight, which is variable from 0% to 96%. A designer can use DELPHI to discover which part of a circuit is preventing his decoder from reaching an acceptable eyeheight performance.

1.1 DELPHI—The Acronym

Defined
Eye
Loss with
Precision
Held
Indication.

2. METHODS CURRENTLY AVAILABLE FOR REDUCING DATA EYEHEIGHT

There are many methods by which the eyeheight of ORACLE data can be reduced for decoder testing purposes. These generally involve some method of distorting the data waveform, either by filtering or by adding a reflection. Adding noise, although it will eventually cause a decoder to fail, is not a good method, because eyeheight cannot be defined in the presence of noise. This is because eyeheight is defined by an algebraic relationship in terms of the data waveform shape, and not in terms of the statistically derived 'decoding margin' following from an assumption of Gaussian noise.

The main criticism of many of the methods of distorting the data waveform is that the relationship between the degree of the distortion and the resulting eyeheight is not well defined. Therefore, for each step change in the distortion, the data eyeheight must be measured by use of an eye-meter.

Some methods of producing a given eyeheight might be unacceptable. For instance, reducing the eyeheight by a low-pass filter is unsatisfactory because some receivers may partly compensate for the filter characteristic. Methods which simulate multipath are favoured, because multipath propagation tends to be the distortion occurring in the field that most affects the reception of ORACLE. However, in many cases, the addition of an echo causes change in the voltage level of the signal. Thus, in order to use the method of echo addition for eyeheight reduction, two controls are needed, one to adjust the echo magnitude and one to keep constant the signal level. The echo delay time is also important; for a given eyeheight, echoes that are very close to the main pulse will cause wider eyes than will echoes that are well separated from the pulse. Since a decoder will decode ORACLE more easily with a wider eye, care must be taken to avoid using any system of eyeheight reduction which allows decoders to perform better than they would in practical off-air conditions. The method used by DELPHI aims at taking account of the above considerations and establishes a simple linear mathematical relationship between cause and effect of the distortion process.

DELPHI produces a narrow eyewidth for a given eyeheight by using well separated echoes; and the method tends to lead to definition of decoder performance in terms of the 'worst case' conditions likely to be experienced in the field.

3. DELPHI: MATHEMATICAL THEORY

Two pieces of basic theory relating to DELPHI will be developed here. The first relates to the method used in DELPHI to linearly reduce the data eyeheight without changing either the pulse-to-bar ratio or the level of the signal. The second relates to the inherent eyewidth reduction.

The second theory predicts the eyewidth of the DELPHI data for each value of eyeheight set on the front panel. Graphs are drawn of eyeheight versus eyewidth for both 70% Nyquist and raised cosine data. A further graph is presented which shows the effective eyeheight as seen by a decoder when using a clock recovered from DELPHI data. In general, the effective eyeheight as seen by a decoder will be less than the input eyeheight value. This is because the clock which is recovered by the decoder will be phase-modulated by intersymbol interference at the threshold crossing time[1,2].

The theories here developed are based upon the important inner eyeheight function and the expression for bar height is developed[3]. The inner eyeheight function is stated below, together with the expression for bar height. The bar height is the reference level attained by the summation of an infinite series of pulses, each separated by time T. Inner eyeheight function:

$$h^{-}(t) = \frac{f(t) - \sum_{K=-\infty}^{\infty}{}' |f(t-KT)|}{b} \tag{i}$$

Bar height function:

$$b = \sum_{K=-\infty}^{\infty} f(t-KT) \tag{ii}$$

3.1. Linear Eyeheight Reduction Theory

If the inner eyeheight function, Equation (i) is used to express the value of the function $f(t)$ at the sampling times nT, the expression reduces to the eyeheight equation by putting $t=0$ Equation (i).

$$h^{-}(0) = \frac{f(0) - \sum_{K=-\infty}^{\infty}{}' |f(KT)|}{\sum_{K=-\infty}^{\infty} f(KT)} \tag{iii}$$

Consider first an elemental data pulse $f(t)$ such that $f(KT) = 0$, with the exception of $T = 0$, when $f(0) = 1$. From Equation (iii):

$$h^{-}(0) = \frac{1-0}{1}$$

here the term $h^{-}(0)$ will be relaxed to simply h

$$h = 1 \tag{iv}$$

ie, the eyeheight is 100%. Note that the pulse-to-bar ratio $f(0)/b = 1$, and that the level of signal given by the bar height b is also unity ($b=1$).

Now consider two echoes of the given elemental pulse $f(t)$ as shown in Fig. 1. Both echoes have a magnitude $af(0)$, and each echo is arranged such that its maximum occurs at a multiple of the sampling

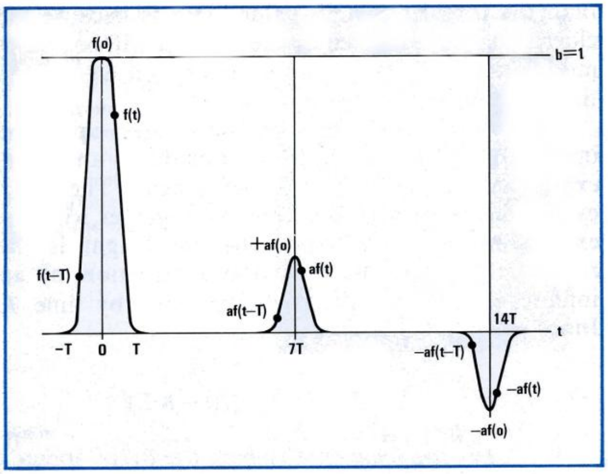


Fig. 1. DELPHI composite pulse.

time, T. The echoes are well separated in time from each other and from the main pulse. This is very important; because, if not so separated, the eyeheight cannot be reduced linearly. In this context, 'well separated' means that each component pulse in the composite waveform has approached zero at the point of touching other components of the composite waveform.

Evaluating the eyeheight Equation (iii) from this composite situation leads to the following:

$$h = \frac{f(0) - [af(0) + af(0)]}{f(0) + af(0) - af(0)}$$

$$= 1 - 2a \qquad \text{(v)}$$

$-$a simple linear relationship between eyeheight and echo magnitude, which is independent of the pulse shape $f(t)$. Note also that, because $b = f(0) = 1$, the pulse-to-bar ratio remains at unity and the signal level is unchanged for all values of eyeheight.

3.2. Eyewidth Reduction Theory

The eyewidth is determined from the inner eyeheight function, Equation (i), as shown in Fig. 2. The eyewidth is computed from the point on the diagram where the inner eye function is zero.

$$\frac{f(t) - \sum_{K=-\infty}^{\infty}{}' f(t-KT)|}{\sum_{K=-\infty}^{\infty} f(t-KT)} = 0$$

Hence, the eyewidth occurs at the point where:

$$f(t) = \sum_{K=-\infty}^{\infty}{}' |f(t-KT)|' \qquad \text{(vi)}$$

The eyewidth is then defined, as in Fig. 2, as the ratio:

$$w = \frac{2t_1}{T} \qquad \text{(vii)}$$

where t_1 is a root of Equation (vi).

For the case where $f(t)$ is a Nyquist pulse, Equation (vi) is too complicated to evaluate, other than by a numerical method on a computer. However, when $f(t)$ is the raised cosine pulse, the root t_1 can be found algebraically.

Expression (vi) for DELPHI with a raised cosine pulse (with reference to Fig. 1) becomes:

$$f(t) = f(t-T) + 2af(t) + 2af(t-T)$$

$$f(t) = \frac{1+2a}{1-2a} f(t-T) \qquad \text{(viii)}$$

For raised cosine data:

For raised cosine $f(t) = \frac{1}{2}\left[1 + \cos\frac{\pi t}{T}\right]$

A trigonometrical identity gives: $f(t-T) = 1 - f(t)$. Substituting these two relationships in Equation (viii) leads to:

$$\cos\frac{\pi t}{T} = 2a$$

and hence:

$$t_1 = \frac{T}{\pi}\cos^{-1}(2a)$$

for the right-hand closure; (the left-hand closure is simply $-t_1$).

The eyewidth is therefore, from Equation (vii):

$$w = \frac{2}{\pi}\cos^{-1}(2a) \qquad \text{(ix)}$$

$-$the relationship between eyewidth and echo magnitude.

Substituting from Equation (v) leads to a relationship between eyewidth, and eyeheight, for a raised cosine pulse (requiring infinite bandwidth):

$$w = \frac{2}{\pi}\cos^{-1}[1-h] \qquad \text{(x)}$$

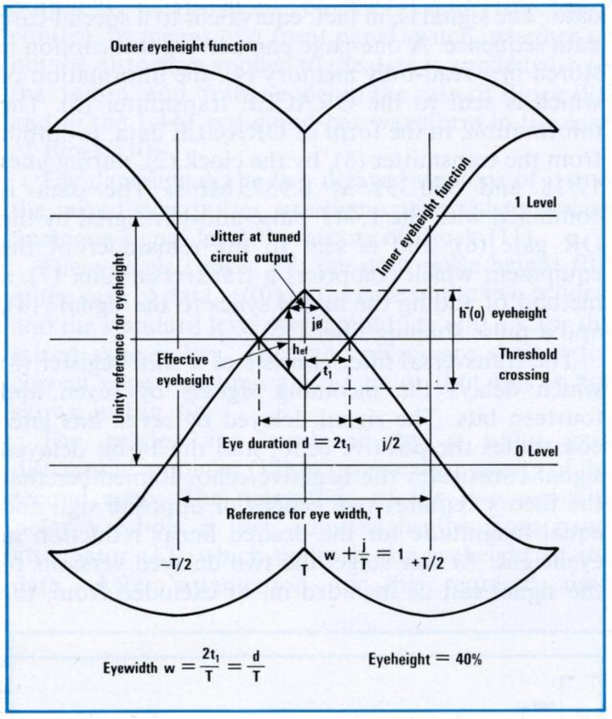


Fig. 2. Computer plot of eyeheight function.

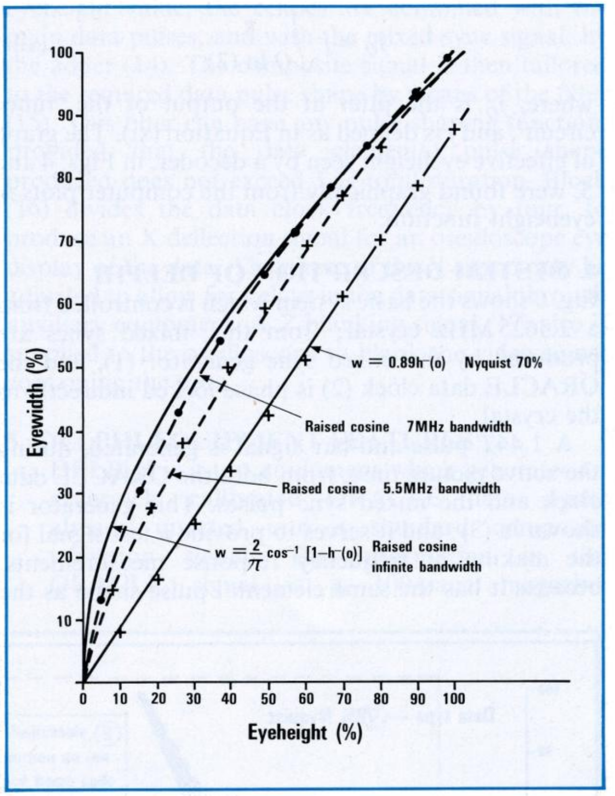


Fig. 3. Theoretical curves of eyewidth versus eyeheight for DELPHI fitted with raised cosine filter and Nyquist 70% filter.

3.3 Computed Eyewidth Function

The inner eyeheight function was calculated by a computer program for DELPHI data at various eyeheight values. These were calculated and plotted by using the method previously described[1]. An example of the plot is shown in Fig. 2.

Plots were made of the 70% Nyquist pulse and of the raised cosine pulse, band-limited to 7 MHz. Measurements of eyewidth were taken from the graphs for each value of eyeheight function plotted. The results are shown in Fig. 3.

3.4. 'Effective Eyeheight' at Decoder due to Clock Timing Jitter

Due to intersymbol interference at the threshold crossing times, any clock recovered from the data will be phase-modulated. The phase modulation, or jitter, which is the peak-peak time of the zero crossings of the data, is related to the eyewidth by the simple expression:

$$\frac{j}{T} = 1 - w \qquad \text{(xi)}$$

where, j = jitter, T = reciprocal of signalling rate, and w = dimensionless eyewidth ratios.

Any consequent clock jitter causes the data to be sampled at points other than at the centre of the eye where the eyeheight is a maximum. The decoder will therefore see an *effective eyeheight*, less than the eyeheight indicated on the DELPHI front panel, due to clock recovery jitter. This is indicated in Fig. 2.

A decoder using the 'tuned circuit' method of clock recovery will reduce the jitter by an amount which depends upon the Q of the 'tuned circuit'. This property of the 'tuned circuit' has been mathematically analysed using a statistical approach[2]. Reference 2 derives a relationship for the reduction of the rms jitter due to the Q of a 'tuned circuit'. This is given as:

$$\frac{j_{rms}^{out}}{j_{rms}^{in}} = \sqrt{\frac{\pi}{Q \ln (2)}} \qquad \text{(xii)}$$

Since rms values of the jitter are difficult to deal with, this report makes the approximation that the maximum value of the jitter will reduce by the same factor. This approximation leads to:

$$j_Q = j\sqrt{\frac{\pi}{Q \ln(2)}} \qquad \text{(xiii)}$$

where, j_Q is the jitter at the output of the 'tuned circuit', and j is defined as in Equation (xi). The graph of effective eyeheight seen by a decoder, in Figs. 4 and 5, were found graphically from the computer plots of eyeheight function.

4. SYSTEM DESCRIPTION OF DELPHI

Fig. 6 shows the basic system which is controlled from a 2.5625 MHz crystal; from this, mixed syncs are produced by the mixed sync generator (1), and the ORACLE data clock (2) is phase-locked indirectly to the crystal.

A 1.44T pulse-and-bar signal is generated, during the active picture time, from both the ORACLE data clock and the mixed sync pulses. This generator is shown in (3); and it serves to provide a test signal for the making of frequency response measurements, because it has the same elemental pulse shape as the data. The signal is, in fact, equivalent to a special-case data sequence. A one-page engineering test caption is stored in a read-only memory (4), the information of which is sent to the ORACLE transmitter (5). The information, in the form of ORACLE data, is output from the transmitter (5), by the clock (2), during lines 17/18 and 330/331 at 6.9375 Mb/s. The data is combined with the 1.44T pulse-and-bar signal by the OR gate (6), and is sent to the remainder of the equipment which comprises a transversal filter (7), a method of adding the mixed syncs to the signal (14), and a pulse shaping filter (15).

The transversal filter consists of a shift register (8) which delays the incoming signals by seven and fourteen bits. The signal delayed by seven bits later constitutes the positive echo; and the 14-bit delayed signal constitutes the negative echo. Remember that the theory requires two echoes of opposite sign and equal magnitude for the desired linear reduction in eyeheight. At this stage, the two delayed versions of the signal can be included in, or excluded from, the

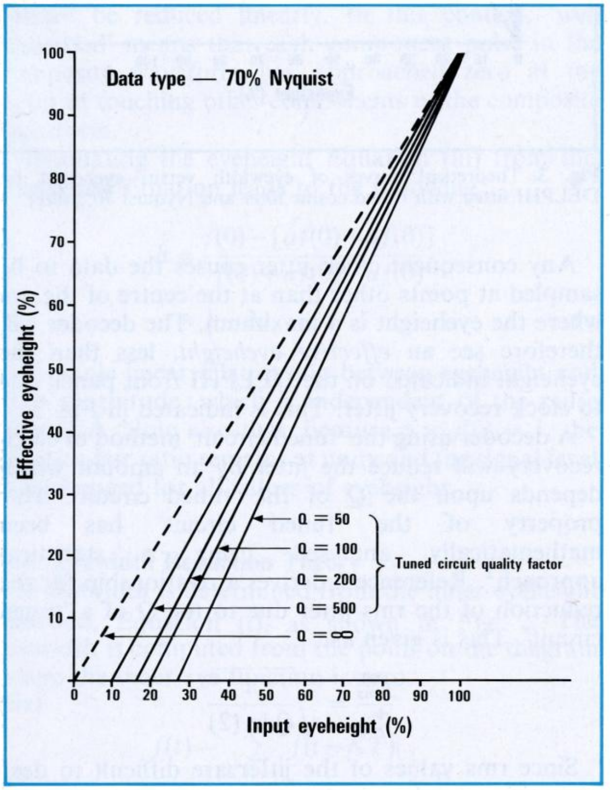


Fig. 4. Graphs of effective eyeheight seen by decoder using a tuned circuit clock recovery circuit, against input eyeheight–computer predicted curves for DELPHI.

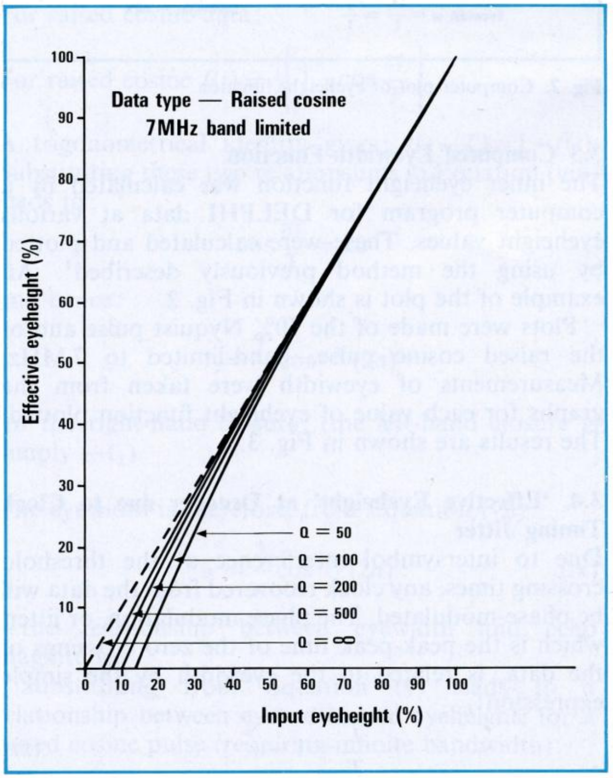


Fig. 5. Graphs of effective eyeheight seen by decoder using a tuned circuit clock recovery circuit, against input eyeheight–computer predicted curves for DELPHI.

output by means of the blocks (9) and (10). These control, by means of a front panel switch, whether or not the distortion applied to the data is applied also to the 'run-in' and 'frame-code' in the case of Block (9), and to the $1.44T$ pulse-and-bar waveform in the case of Block (10).

The data signal, the two delayed versions of it and the mixed sync pulses, are then converted to precise analogue signal levels by means of Block (11).

These levels consist of: the data pulse height $f(0)$ in the case of data, $af(0)$ in the case of the two echoes, and the standard level sync amplitude of 0.3 V for the mixed sync pulses. The sync pulses are shaped for correct edge rise time at this point (but this is not shown in Fig. 6).

The echoes are combined by a unity gain differential amplifier (12) to reverse the polarity of the second echo. The magnitude of the two opposite polarity echoes is then adjusted by the front panel attenuator (13) which controls the eyeheight of the data. After attenuation to the required data eyeheight value, the echoes are combined with the main data pulses, and with the mixed sync signal, by the adder (14). The composite signal is then tailored to the required data pulse shape by means of the filter (15). This filter can have any pulse shaping function, provided that the data elemental pulse shape produced does not exceed 1 μs total duration. Block (16) divides the data clock frequency by four, to produce an X deflection signal for an oscilloscope eye display of the data. The phase of the X signal may be adjusted to allow for delays in the data signal through auxiliary equipment. A Z blanking signal (17) also is supplied to the oscilloscope to blank the video signal containing the data.

5. DELPHI EQUIPMENT FEATURES

(*a*) DELPHI is a test equipment which generates an accurately calibrated ORACLE data signal already inserted into a standard composite television signal. The information in the ORACLE signal is a 100-page magazine

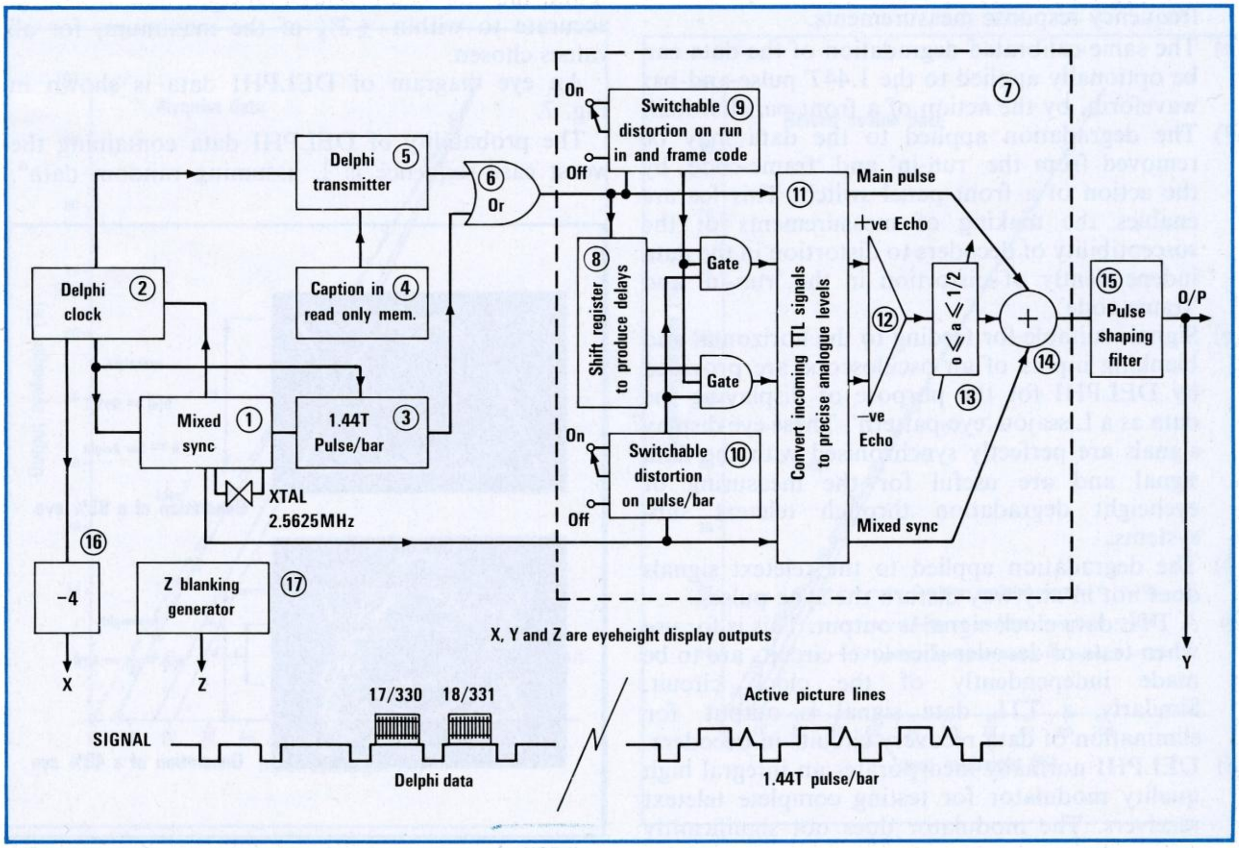


Fig. 6. Block diagram of DELPHI.

consisting of a repeated one-page caption stored in the DELPHI programmable memory.

(*b*) DELPHI equipment generates ORACLE data with an accurately determined eyeheight which is easily adjusted, by a front panel control, over the continuous range 0% to 96% (tolerance ±2%). The value of the selected eyeheight is clearly indicated on the front panel display. Since the equipment generates an accurately combined video and teletext signal from a crystal controlled source, no other expensive auxiliary video test equipment is needed for teletext test purposes.

(*c*) ORACLE data may be generated to any specific filtering function. At present, DELPHI is fitted with the 70% Nyquist filter, as recommended in the Broadcast Teletext Specification, September 1976. It is also fitted with the raised cosine pulse shaping filter. These filters generate an eyeheight of 96%, the maximum for DELPHI.

(*d*) A teletext $1.44T$ pulse-and-bar waveform is present on all active picture lines, and is filtered as in (*c*) above. This waveform is useful for frequency response measurements.

(*e*) The same calibrated degradation of the data can be optionally applied to the $1.44T$ pulse-and-bar waveform, by the action of a front panel switch.

(*f*) The degradation applied to the data may be removed from the 'run-in' and 'frame-code' by the action of a front panel switch. This feature enables the making of measurements of the susceptibility of decoders to distortion in the data independently of distortion in the 'run-in' and 'frame-code'.

(*g*) Signals suitable for feeding to the horizontal and blanking inputs of an oscilloscope are provided by DELPHI for the purpose of displaying the data as a Lissajou 'eye-pattern'. These eye display signals are perfectly synchronised with the data signal and are useful for the measuring of eyeheight degradation through teletext sub-systems.

(*h*) The degradation applied to the teletext signals does not in any way disturb the sync pulses.

(*i*) A TTL data clock signal is output. This is for use when tests of decoder slice level circuits are to be made independently of the clock circuit. Similarly, a TTL data signal is output, for elimination of data recovery circuits in decoders.

(*j*) DELPHI normally incorporates an integral high quality modulator for testing complete teletext receivers. The modulator does not significantly reduce the data eyeheight.

6. DELPHI: EXPECTED AREAS OF USE

(*a*) As a laboratory eyeheight standard and reference source of data for calibrating eyeheight measuring equipment.

(*b*) As a method of measuring the teletext performances of broadcast network components, eg, data bridges, signal distribution equipment, British Telecom links and television transmitters.

(*c*) As a design aid to manufacturers of broadcast quality equipment.

(*d*) As a design aid to teletext decoder manufacturers.

(*e*) As a method of production line acceptance testing for teletext equipment.

(*f*) As a compact and portable source of video signals containing teletext data of variable eyeheight.

Various test arrangements using DELPHI are shown in the figures of the Appendix.

7. RESULTS

A prototype model of DELPHI, based on the system described in Section 4, has been constructed. It was found that the front panel eyeheight indication was accurate to within ±2% of the maximum, for all values chosen.

An eye diagram of DELPHI data is shown in Fig. 7.

The probability of DELPHI data containing the worst case sequence is $\frac{1}{4}$, assuming random data[4].

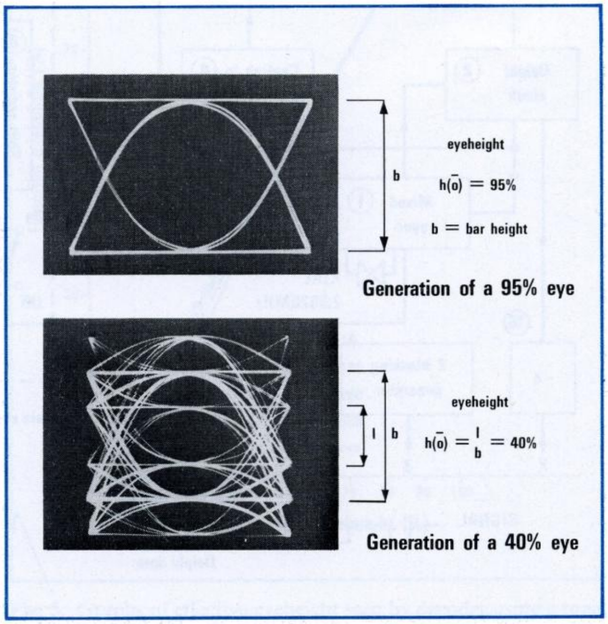


Fig. 7. Photographs of eye diagrams of data produced by DELPHI.

Therefore, it is certain that any DELPHI caption will contain many eye-height sequences of worst case. However, different captions may contain different worst case eyewidth sequences. It is therefore important to standardise on one caption. In this connection, captions which have an orderly format, allowing immediate recognition of errors and omissions, are much preferred to 'random data' captions.

7.1. Eyewidth Versus Eyeheight Relationship

Figure 3 shows the theoretical curves of eyewidth versus eyeheight for DELPHI. The equation for eyewidth derived in Section 3.2, for ideal raised cosine data with an infinite bandwidth, is shown together with two eyewidth curves of raised cosine and Nyquist data measured from the computer plots. The curve for raised cosine, band-limited to 7 MHz by the computer program, compares favourably with equation derived in Section 3.2; the discrepancy being due to the different bandwidths considered. The computer calculated values of the 70% Nyquist data show a relationship which is quite closely linear. The following two equations could therefore be used to relate eyewidths to eyeheights for DELPHI data at 7 MHz bandwidth. The raised cosine equation is an approximation at low eyeheights.

$$\text{Raised cosine } w \simeq \frac{2}{\pi}\cos^{-1}(1-h) \qquad \text{(xiv)}$$

$$70\%\ \text{Nyquist } w = 0{\cdot}89\,h \qquad \text{(xv)}$$

7.2. Effective Eyeheight Performance of a Decoder

Figures 4 and 5 show curves, derived from those of Fig. 3, predicting the effective eyeheight performance of a decoder recovering the data clock by a tuned circuit, for various Q values of the tuned circuit. The concept of an 'effective eyeheight' allows assessments to be made of the performance of any such decoder—to a large extent—without need of considering the effects of data shape and clock recovery jitter.

To test these curves, measurements were made of the IBA eye-meter[6] for both raised cosine and 70% Nyquist data from DELPHI. The IBA eye-meter has a fixed slice-level data detector.

Figures 8 and 9 show a comparison between the

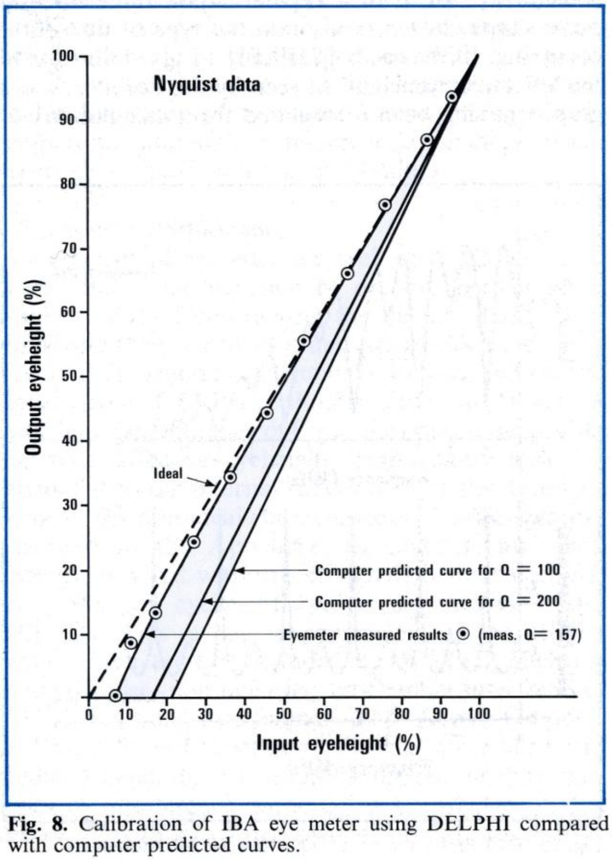


Fig. 8. Calibration of IBA eye meter using DELPHI compared with computer predicted curves.

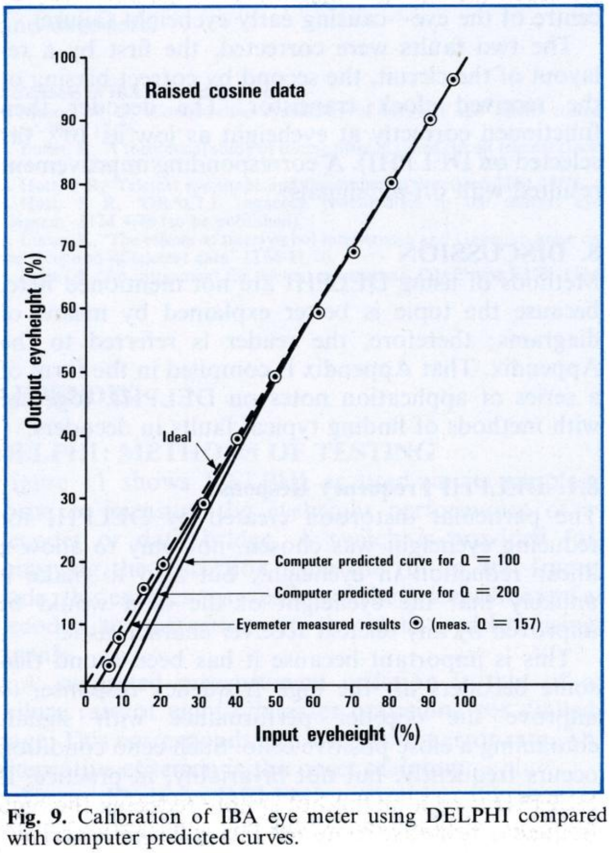


Fig. 9. Calibration of IBA eye meter using DELPHI compared with computer predicted curves.

computer-predicted curves and the measured performance. The discrepancies are mainly attributable to approximations made in the theory (see, in particular, Section 3.4); the theory tending always to predict a less favourable eye-meter performance than is observed in practice.

7.3. Commercial ORACLE Decoder Improvements Using DELPHI

The performance of a commercial video-to-video ORACLE decoder was improved by use of DELPHI. When the decoder was first measured it failed to decode correctly when the eyeheight of the DELPHI signal was less than 45%. Using DELPHI, two problems in the decoder design were found. First, internally generated noise from logic signals inside the decoder interfered with the sensitive data capture circuits. Secondly, and more seriously, in the clock recovery circuit, the transistor which supplied current to the tuned circuit was being switched off during the negative half-cycles of the recovered clock. This caused the received clock to be phase-modulated and to clock the data at a position removed from the centre of the eye—causing early eyeheight failure.

The two faults were corrected, the first by a re-layout of the circuit, the second by correct biasing of the received clock transistor. The decoder then functioned correctly at eyeheight as low as 10% (as selected on DELPHI). A corresponding improvement resulted with off-air signals.

8. DISCUSSION

Methods of using DELPHI are not mentioned here, because the topic is better explained by means of diagrams; therefore, the reader is referred to the Appendix. That Appendix is compiled in the form of a series of application notes on DELPHI, together with methods of finding typical faults in decoders.

8.1. DELPHI Frequency Response

The particular distortion created by DELPHI for reducing eyeheight was chosen, not only to allow a linear reduction in eyeheight, but also to make it unlikely that the eyeheight of the data would be improved by any teletext receiver characteristic.

This is important because it has been found that some decoders lift the high frequency response, to improve the decoder performance with signals containing a close positive echo. Such echo condition occurs frequently, but not invariably, in practice. If DELPHI used a method of simply reducing the high frequency response to adjust the eyeheight, receivers of that particular type might compensate for DELPHI. It is undesirable that a decoder shall improve the performance as measured on DELPHI; because DELPHI is an equipment designed to cover signal distortions of any type. The actual frequency distortion introduced by DELPHI at various eyeheights is shown in Fig. 10, wherein it can be seen that, at low eyeheights, DELPHI produces very severe notches in the frequency spectrum. Therefore, any slight slopes in the amplitude spectrum produced by the decoder at high frequencies will not significantly affect the value of the data eyeheight.

One important requirement disclosed by the work on DELPHI is the necessity of an eyewidth measurement when assessing decoder performance. Figures 4 and 5 show that, although the decoder performance will be similar for 'effective eyeheight' measurements produced from different types of data, the 'actual eyeheight' values input to the decoder, at the point of onset of errors, will be dependent upon the eyewidth of the input data signal. The eyewidth measurement will be dependent on the data waveform; this in turn depends upon the elemental pulse shape chosen, and upon the type of distortion occurring. In the case of DELPHI, Figs. 4 and 5 give the 'effective eyeheight' as seen by the decoder; these graphs having been formulated from calculations of

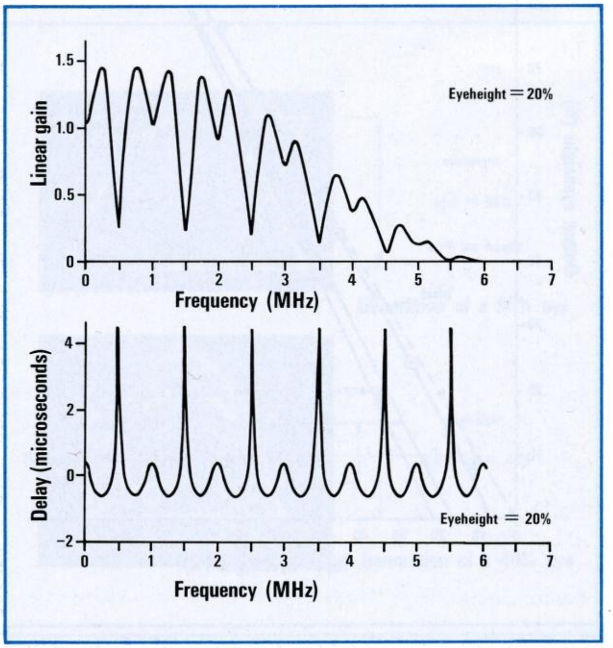


Fig. 10. DELPHI I spectrum, 70% Nyquist filter fitted.

the DELPHI data eyewidth for various eyeheights of both 70% Nyquist and raised cosine data.

The correlation between the performance of a decoder with field data signals and the measured DELPHI performance is important. From practical experience to date, it is thought that, for any given decoder sample, DELPHI results tend to agree with the worst observed field performance of that decoder.

8.2. Effective Eyeheight Performance of a Decoder

Section 7.2 tends throughout to indicate a less favourable decoder performance than is obtained in practice. However, the theory does confirm that the effective eyeheight of a decoder departs further from the ideal as the input eyeheight is reduced. It also confirms that the raised cosine curve departs less from the ideal than does the Nyquist curve. The theory indicates that the effect of the reduced eyewidth upon the decoder performance becomes less as the Q of the tuned clock recovery circuit increases. However, practical tests have shown that a Q of approximately 150 is an optimum. This is because a Q which is too high causes an increase in the error in the clock phase with respect to the centre of the eye. This effect occurs because the rate of change of phase, with change of centre frequency, increases as the Q increases. As the centre frequency of the tuned circuit changes with temperature and with setting error, larger clock phase errors then occur with higher Q values.

8.3. Decoder Performance

The concept of an 'effective eyeheight' allows, to a large extent, the assessing of decoder performance without need of considering the details of the data shape and the jitter of its tuned circuit clock recovery circuit. As a general rule, an ideal decoder, fed with a signal from DELPHI, should have an 'effective eyeheight' performance of 0% at the onset of errors. A non-zero 'effective eyeheight' performance may be attributed to the internal functioning of the decoder. Some of the non-ideal characteristics of a decoder are discussed in the Appendix. In practice, an ideal decoder may fail with off-air signals before reaching the 'effective eyeheight' value as measured on DELPHI. This is due to parameters of the off-air signal which are not included in DELPHI, such as thermal noise, non-linearity, co-channel interference (CCI), ignition interference and hum. Decoder performance as a function of thermal noise has been studied[5]. Separate tests would be needed for the other types of interference, although a knowledge of the decoder design may often provide an indication. For example, a peak detection adaptive slice circuit will be almost insensitive to CCI, whereas a circuit which uses only the data run-in for slice level adaption will be very sensitive. However, the latter would provide the better performance in the presence of data containing non-linear distortion.

9. CONCLUSIONS

9.1. The DELPHI waveform is unique in that it incorporates many useful properties within a single teletext test signal.

9.2. DELPHI is a signal generator, contained as a single and compact unit, and it serves to replace a vast array of teletext testing equipment previously required. In addition, it provides a range of exacting test waveforms and functions which, hitherto, have not been available.

9.3. The teletext signal generated by the DELPHI instrument enables application of searching tests to teletext equipment and is precisely repeatable.

Hence, the signal generated by DELPHI is recommended as a *standard reference* for the making of performance measurements of teletext receivers and decoders.

References to IBA Internal Reports

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3. Hutt, P R, 'Teletext eye-shape and the eyeheight function'–ITM 13/76.
4. Hutt, P R, 'ORACLE sequence probabilities in the teletext eye diagram'–ITM 4/76 (to be published).
5. Lucas, K, 'The effects of intersymbol interference and Gaussian noise on the reception of teletext data'–ITM 11/76.
6. Dean, A, 'An instrument for teletext eye analysis DME type E358'–ITM 1/78.

APPENDIX

DELPHI: METHODS OF TESTING

Figure 11 shows DELPHI as used, in its simplest form, to measure the eyeheight performance of a decoder or data bridge. A switch is provided for removing the distortion from the run-in and frame code; this enables easy testing of the susceptibility of a decoder to distortion of the data synchronising signals.

A suggested measurement criterion is that of a failure rate of eight character omissions per dialled page. This corresponds to a 1-in-10^3 bit error rate. An alternative criterion is the onset of errors.

Figure 12 shows DELPHI as used in calibrating a teletext subsystem. The subsystem could be anything

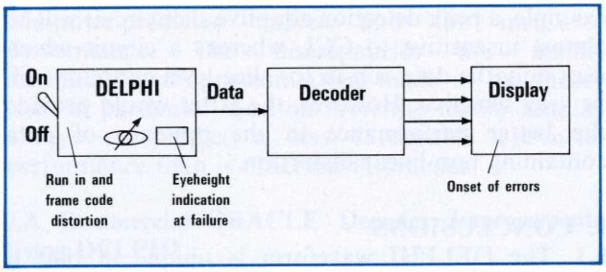


Fig. 11. Measurement of decoder eyeheight performance.

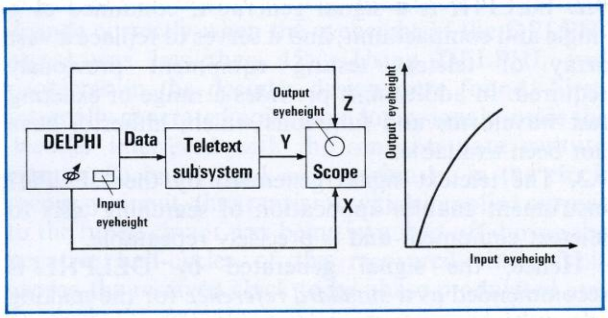


Fig. 12. Measurement of eyeheight transfer function of a Teletext subsystem.

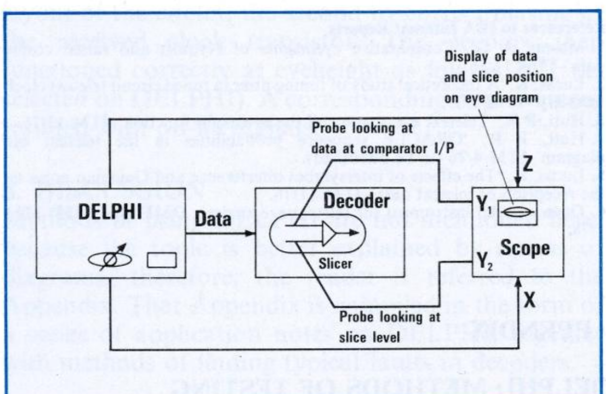


Fig. 13. Analysis of slice circuit performance at various input eyeheight values.

from an eye-meter to a television transmitter. A graph of input versus output eyeheight could be plotted by using the front panel eyeheight indication for the input value; and the Lissajou display, driven horizontally by the *X*-deflection signal from DELPHI, for the output value. Graphs of input versus output eyewidth also could be plotted.

Measurements of a transmitter would be made via an output from the station demodulator to the oscilloscope.

Figure 13 shows the detailed analysis of the slicing circuit of a decoder at various input eyeheight values. By using a probe and the *X* output of DELPHI, an eye display can be obtained of the data at the slicer. With the use of a further probe, the position of the slice level can be measured with respect to the data eye, for all values of eyeheight. This would be useful for adaptive methods of slicing, by enabling observations as to whether the adaption process produces the correct slice level as the eyeheight is reduced.

Further to that, the position of the clock could be measured with respect to the centre of the eye. This would show whether the phase of the clock had been changed with reduction in eyeheight, or by movement of the slice level, due to the adaption process.

The eye display would show any internally generated noise, e.g., TTL interference on the data and slice waveforms, which would modulate the relative positions of the slice level and of the data, and so cause incorrect decoding.

Figure 14 shows replacements of the clock recovery circuit by the transmit clock from DELPHI. This

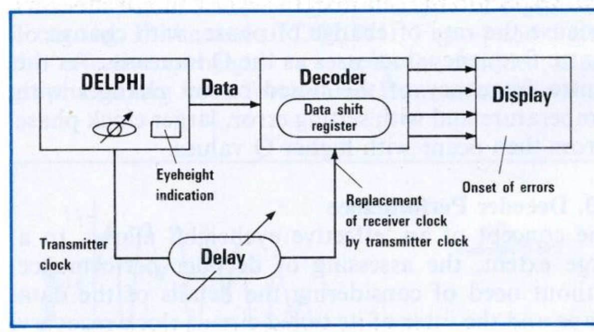


Fig. 14. Measurement of slice circuit performance by eliminating the receiver clock.

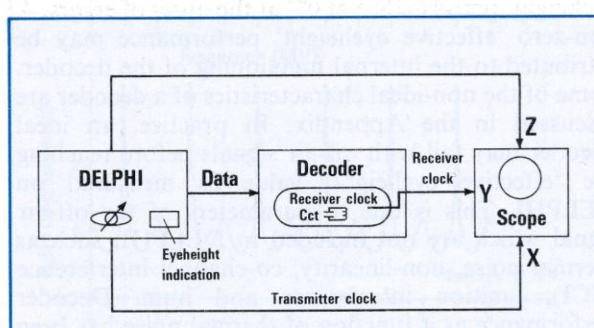


Fig. 15. Measurement of receiver clock jitter at various eyeheight values.

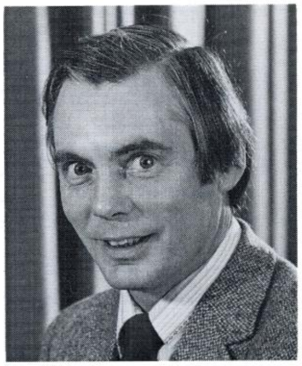
affords elimination of clock recovery problems and enables testing of decoder performance based solely on the slice circuit.

Similarly, the data can be obtained directly in TTL form from DELPHI, and the functioning of the decoder due to the clock recovery circuit can be tested.

Figure 15 shows respectively, the transmit and receive clocks, from DELPHI and from a decoder, being displayed as a Lissajou pattern. Phase modulation of the receiver clock can be observed as the eyeheight of the data is reduced.

Digital Audio Signal Processing by Microcomputer

by J B Watson



JOHN WATSON B.Eng, CEng, MIEE, graduated from Liverpool University. He began his career in the broadcasting field with Rediffusion Research Ltd. Subsequently he moved to Plessey, at Ilford, to work on military communications systems. Before joining the IBA as a Senior Engineer in 1970 he spent some time applying electronics to industrial processes in the food/mineral sorting and tobacco industries. At the IBA he has worked in both SD&C and E & D Departments, on telemetry and remote control systems. He was project leader for the development of the first Oracle captions generator and for the digital automatic measuring equipment (DAME) believed to be the first application of microcomputers in broadcasting. Currently he is working on digital audio tape recording for digital VTR, and on proposals for satellite audio and data broadcasting. He is a member of EBU Specialist Group V1-AUD, concerned with future digital audio standards. He plays chess for the IBA team; his hobbies are photography and home computing and he lives in Romsey.

Synopsis

The author suggests that audio frequency signal processing is the most recent area in broadcasting to benefit from digital technology. He lists the currently accepted digital sampling characteristics which limit the reduction of programme modulation noise, idle-channel noise, distortion and wow and flutter. The article includes a brief review of the development of microcomputers, compares analogue and digital companding and describes how companding is affected by use of a microprocessor.

INTRODUCTION

From the point of view of the broadcasting industry, there can be no doubt that digital technology carries with it numerous benefits to both listener and viewer, more than compensating for the additional complexity and expense of the signal origination and transmission plant involved.

Audio-frequency and signal processing is the latest 'beneficiary' (or 'victim', depending on one's degree of conservatism) of the digital electronics revolution brought about by the ubiquitous silicon chip.

Those who possess or have heard demonstrated audio discs cut from a digitally recorded master tape facility can confirm the significant improvements in clarity and fidelity now obtainable. This is in spite of the fact that the digital processing component here represents only a small part of the total recording/reproduction system. Further developments in laser optical recording may, in the future, finally resolve the contentious question of what truly constitutes 'high fidelity' audio by providing, for all practical purposes, absolute fidelity between recording studio and listening auditorium.

Digital Audio Characteristics

Reasons for the subjective superiority of digital audio over the traditional analogue equipment are its much reduced programme modulation noise, idle-channel noise, distortion and wow and flutter. The magnitudes of these improvements are determined by the digital sampling characteristics, minimum standards for which are generally accepted to be, for broadcasting:

1. Sampling rate: 32 000 samples/second

2. Digital resolution: 14-bits/sample
3. Pre/de-emphasis: CCITT characteristic.

Pre-emphasis and de-emphasis are not essential with digital audio, but give worthwhile improvement in high-frequency noise performance for signals possessing limited energy at the upper end of the audio spectrum.

These standards provide for an audio-channel bandwidth to 15 kHz (provided that great care is taken in the manufacture of the anti-aliasing filter), and a signal/noise ratio of better than 85 dB. The needs of the recording studios, where the final output is derived from a large number of independent sources, are more stringent; hence the use of 16-bit sampling at rates of between 48 000 and 64 000 per second in order to minimise signal degradation through the mixing processes.

ADC Considerations

The following specification figures underline the reasons for the relative delay between the general acceptance of digital video and digital audio technology. For example, the 'aperture time' required of an 8-bit 5 MHz video sampling circuit, is only 20% shorter than that for a 16-bit 15 kHz audio sampler; but the precision of the audio circuit needs to be better by a factor of 256. Thus, although proprietary video analogue-to-digital converters (ADCs) have been obtainable for the past three or four years, audio ADCs with adequate performance have only recently become available. Table 1 shows the specification of such a device. Although sufficiently accurate and sufficiently fast for broadcast-quality audio, this ADC (in common with many other proprietary units) has the disadvantage of 'offset-binary' digitally-coded outputs (see Table 2). This means that the most critical zone in its transfer characteristic occurs at the mid-point, where the digital output changes from 011...111 to 100...000. Since this is normally the quiescent operating region, careful circuit layout and screening are essential for the minimising of digital-analogue crosstalk. A more suitable coding technique for digital audio is the sign-plus-magnitude arrangement, shown in Table 2, which has the effect of moving the most critical region away from the quiescent operating point.

Digital-to-analogue converters (DACs) are usually less costly than the corresponding ADCs, but can

TABLE 1: SPECIFICATION FOR A PROPRIETARY ADC DEVICE SUITABLE FOR BROADCAST-QUALITY DIGITAL AUDIO

Analogue-to-digital Converter Type MP8016, Analogic:	
Input Voltage Range:	– 10V to + 10V bipolar
Input Impedance:	5·0 k
Digital Resolution:	16 bits
Relative Accuracy:	± 0·0015% of Full scale
Absolute Accuracy:	± 0·003% of Full Scale
Quantizing Error:	± ½ least sig. bit
Monotonicity:	Guaranteed
Recommended Calibration Interval:	6 months
Warm-up Time to Specified Accuracy:	10 minutes
Conversion Time:	0·6 to 2·0 μs per bit (adjustable)
Digital Output Code:	Offset binary or Two's Complement
Power Supplies:	± 15V, 65 mA and + 5 V, 300 mA
Dimensions:	102 × 77 × 13 mm

TABLE 2: COMPARISON OF OFFSET-BINARY AND SIGN-PLUS-MAGNITUDE ADC OUTPUT CODES

The offset binary code is easier to implement in hardware, and is the one most commonly used in proprietary ADCs. The sign-plus-magnitude code may be more suitable for an audio ADC, but suffers the disadvantage of two equally-valid codes for zero input.

Offset Binary Code:

1111	1111	1111	1111 =	+ 9·9997	Volts	input
1000	0000	0000	0001 =	+ 0·0003	,,	,,
1000	0000	0000	0000 =	0·0000	,,	,,
0111	1111	1111	1111 =	– 0·0003	,,	,,
0000	0000	0000	0000 =	– 10·0000	,,	,,

Sign + Magnitude Code:

0111	1111	1111	1111 =	+ 9·9997	Volts	input
0000	0000	0000	0001 =	+ 0·0003	,,	,,
0000	0000	0000	0000 =	0·0000	,,	,,
1000	0000	0000	0000 =	0·0000	,,	,,
1000	0000	0000	0001 =	– 0·0003	,,	,,
1111	1111	1111	1111 =	– 9·9997	,,	,,

introduce non-linearity into the audio channel if their output circuits are 'slew-rate limited'. This problem disappears if the DAC output is re-sampled by a sample-and-hold device designed specifically for audio applications[1].

Signal Processing by Microcomputer

Before considering in detail the type of audio signal processing appropriate to microcomputers, it may be instructive to consider the history of the development of these devices since their introduction about eight or nine years ago. Table 3 summarises the characteristics of three 'generations' of microprocessor originating from a single manufacturer, the demarcations corresponding loosely with the fabrication of the silicon chip by P-channel, N-channel and H-MOS technology. Details of a prospective 32-bit device are also included.

Of particular relevance to audio processing are the parameters relating to accumulator capacity (16-bits being desirable), instruction cycle time and interrupt response time (latency). First generation devices (4004, 4040, 8008) were relatively slow in operation, offering instruction times of several microseconds, and possessing extremely limited—or, in the case of the 4004, non-existent—interrupt handling capability. Real-time processing of broadcast quality digital audio signals was not feasible with these processors, although the 8008 did find application in the military communications field as a speech processor.

Second generation processors, such as the still-current 8085, exhibit speed improvements of an order of magnitude over their predecessors. With an instruction cycle time of 1·3 microseconds, between 12 and 24 simple processing steps can be undertaken in the interval separating adjacent audio samples (this varies from 30 to 15 microseconds, for sampling rates of between 32 000 and 64 000 per second). Interrupt latency is of a low order, allowing rapid re-programming of peripheral devices after the treatment of blocks of data. Self-contained hardware multiply and divide features, however, are not typical of second generation microprocessors. Complex digital filtering in the audio frequency band, therefore, is not generally possible, with the exception of certain filtering operations requiring weighting factors related by integral powers of two. On the other hand, digital audio companding can be implemented with this type of processor, since the essential feature of a companding algorithm is a multiple-bit shifting operation.

Extremely powerful processing possibilities are now

TABLE 3. COMPARISON OF THREE GENERATIONS OF MICROPROCESSOR FROM A SINGLE MANUFACTURER.

The 8088 is a development of the 16-bit 8086, but communicates via an 8-bit data bus.

	'FIRST GENERATION' (P-MOS technology)			'SECOND GENERATION' (N-MOS technology)		'THIRD GENERATION' (H-MOS technology)		FUTURE
Microprocessor Type	4004	8008	4040	8080	8085	8086	8088	iAPX 432
Date Introduced	1971	1972	1974	1974	1976	1978	1979	1981
Accumulator Capacity	4-bits	8-bits	4-bits	8-bits	8-bits	16-bits	16-bits	32-bits
No. of Instructions	46	48	60	111	113	300+	300+	very many
Min. Instruction Cycle Time	10·8 µs	20 µs	10·8 µs	2 µs	1·3 µs	0·4 µs	0·4 µs	0·1 µs
Memory Addressing Capability	4 k × 8	16 k × 8	8 k × 8	64 k × 8	64 k × 8	1 M × 8	1 M × 8	4000 M × 8
No. of General Purpose Registers	16 × 4-bit	7 × 8-bit	24 × 4-bit	7 × 8-bit	7 × 8-bit	12 × 16-bit	12 × 16-bit	?
Power Supplies	+5V, −10V	+5V, −9V	+5V, −10V	±5V, +12V	+5V	+5V	+5V	+5V
Sub-routine Nesting Levels	3	7	7	unlimited	unlimited	unlimited	unlimited	unlimited
No. of Interrupt Types	0	1	1	8	12	256	256	none
Interrupt Latency (approx.)	—	40 µs	30 µs	6 µs	4 µs	12 µs	12 µs	—
Address, Data Bus Width	12 addr. 4 data 4 RAM sel	14 addr. 8 data	12 addr. 4 data 4 RAM sel 2 ROM sel	16 addr. 8 data	16 addr. 8 data	20 addr. 16 data	20 addr. 8 data	32 addr. 32 data

available, following the introduction of the 8086 and other similar devices such as the Z8000 and M68000. These computers operate directly on 16-bit sampled data values, have fast and comprehensive instruction repertoires including hardware multiply and divide, and can directly address memory arrays in excess of a million bytes. The very complex nature of these machines, however, necessitates some compromise in performance in the real-time environment, the most serious being an interrupt latency approaching the 15 to 30 μs sampling interval of high-quality audio.

This arises from the extended memory addressing and interrupt type handling capabilities. The 8086 computer, for example, responds to an interrupt by storing the current program counter and memory segment register (16-bits each), calculating the location of the appropriate interrupt vector, and reloading new program count and segment values from the vector location. Flexibility of operation is thus achieved at the expense of speed, the complete process occupying approximately 12 μs. This trend is likely to continue with the emergence of new device types (e.g., iAP 286) capable of directly addressing thousands of megabytes of memory. Future microprocessors designed for 'mainframe' applications might dispense entirely with interrupt facilities, since these prejudice the 'number crunching' performance.

The solution to this problem, in the critical real-time signal processing area, is in the use of dedicated input/output processors. These are intended specifically for rapid peripheral device servicing duties, and communicate with the main processor system via block transfers on direct-memory-access channels. Operating speed improvements anticipated with the H-MOS process are also likely to simplify the task of the digital audio engineer.

Digital Companding

An example of the type of digital audio processing now possible with microcomputers occurs in signal compression and expansion (companding). Analogue companding is used extensively in the magnetic tape recording of music, where it provides an improved signal/noise ratio, particularly at high frequencies. The widespread acceptance of the Philips audio cassette as a satisfactory medium for domestic sound recording is, in fact, largely due to the adoption of 'Dolby' or similar companding techniques.

Analogue systems of this type separate the incoming audio signals into several frequency bands, each channel during recording being compressed by amounts depending upon the peak levels present in each appropriate spectral band. The accuracy of the reciprocal expansion process during playback is seldom perfect, since great reliance is placed on carefully matching the filters, time constants and level-dependent amplifiers, in the record/replay chains.

The processes involved with digital companding are, on the other hand, accurately reversible. The degree of compression applied by the encoder is transmitted, together with the audio sample values, along a separate time-multiplexed channel to the decoder. No gain errors or time constant mismatching errors occur, but a degree of programme-modulation noise is introduced, the magnitude of which is governed by the type of digital companding used. It might seem paradoxical that digital companding apparently worsens the audio signal/noise ratio, whereas analogue companding improves it. This arises from the different areas of application in which the two techniques find justification, digital companding being used in bandwidth reduction rather than noise reduction. Alternatively, the companding process can be regarded as a 'trade-off' between idle-channel (background) noise and modulation noise in a channel of defined capacity or bandwidth. This 'trade-off' takes place in both analogue and digital companding, as sensitive ears can easily recognise, and there is, therefore, no paradox.

Many different types of digital companding have been proposed, these being within two main categories of 'instantaneous' and 'near-instantaneous' (or 'quasi-instantaneous') form. Table 4 depicts the operation of a simple 'A-Law' instantaneous compander, used for reducing to 10-bits per sample a 14-bits per sample audio signal. The companding algorithm is simply expressed as follows: The position of the most significant '1' digit in the 14-bit data word is a measure of the signal magnitude within a 2 : 1 range. A 3-bit digital code representing the number of leading (more significant) '0' bits in each word is transmitted with the word, the leading zeros and the most significant '1' being suppressed. The remainder of the digital word is transmitted with a precision of seven bits, with the less significant bits truncated.

The resulting signal comprises ten bits per sample, three bits of which define the approximate value, within a 2 : 1 range, and seven the more precise magnitude within that range. One of the seven bits indicates the signal polarity. Digital sample values with more than five leading zeros experience no

TABLE 4: 14 : 10 A-LAW COMPANDING

14-bit audio samples are compressed before transmission to a 6-bit representation (X's in the Table), the less significant bits being truncated (shown as T's in the table). A 3-bit scale factor indicating the audio level within a range of 2 : 1 is appended. Finally, the 'sign' bit (13) is added, making 10 bits altogether. A refinement of the procedure is to 'round-up' the levels by one half least significant bit to improve accuracy.

A-LAW RANGE No.	SCALE FACTOR	msb						Bit No.					lsb		
		13	12	11	10	9	8	7	6	5	4	3	2	1	0
7	1 1 1	0	1	X	X	X	X	X	X	T	T	T	T	T	T
6	1 1 0	0	0	1	X	X	X	X	X	X	T	T	T	T	T
5	1 0 1	0	0	0	1	X	X	X	X	X	X	T	T	T	T
4	1 0 0	0	0	0	0	1	X	X	X	X	X	X	T	T	T
3	0 1 1	0	0	0	0	0	1	X	X	X	X	X	X	T	T
2	0 1 0	0	0	0	0	0	0	1	X	X	X	X	X	X	T
1	0 0 1	0	0	0	0	0	0	0	1	X	X	X	X	X	X
	0 0 0	0	0	0	0	0	0	0	0	X	X	X	X	X	X

compression and are therefore expanded without loss of resolution. For signals of larger magnitude, the compression takes the form of a truncation of the less significant bits, giving rise to coarser quantizing steps and associated programme modulation noise. Listeners accustomed to the very high sound quality reproduced by digital systems have observed that, with experience, their threshold of tolerance to modulation noise tends to decline. Acceptable standards of performance based on subjective tests may, therefore, become more stringent as the use of digital audio equipment increases.

'Near-instantaneous' companding makes more efficient use of the available channel capacity, and thus achieves a lower level of modulation noise. By deriving scale factors related to the peak amplitudes of groups of audio samples, rather than to individual sample values, more capacity is available for accurately resolving the signal levels. In two systems recently proposed[2,3], groups of samples representing a duration of approximately 1 ms are examined before defining the degree of companding appropriate to the group as a whole. Subjective comparison tests of various digital companders tend to the conclusion that the 'near-instantaneous' principle provides a standard of performance equivalent to that of an 'instantaneous' system employing at least one more bit per sample. Many of the differences between the various contending schemes proposed for international programme exchange arise from attempts by their proponents to make maximum use of the different hierarchical levels available on Posts, Telegraphs and Telephones (PTT) networks. Until detailed plans for digital sound channels are published by the PTT authorities, however, an optimum transmission system is unlikely to be realised. Tariff structures are likely to play a more important role than technical reasons in deciding which form of companding, if any, should be universally adopted.

Companding by Microprocessors

Since both 'instantaneous' and 'near-instantaneous' companders employ the same basic principle in deriving their respective scale factors, i.e., the determination of the position of the most significant bit in a digital code, it is possible to devise hardware configurations capable of operating in either mode.

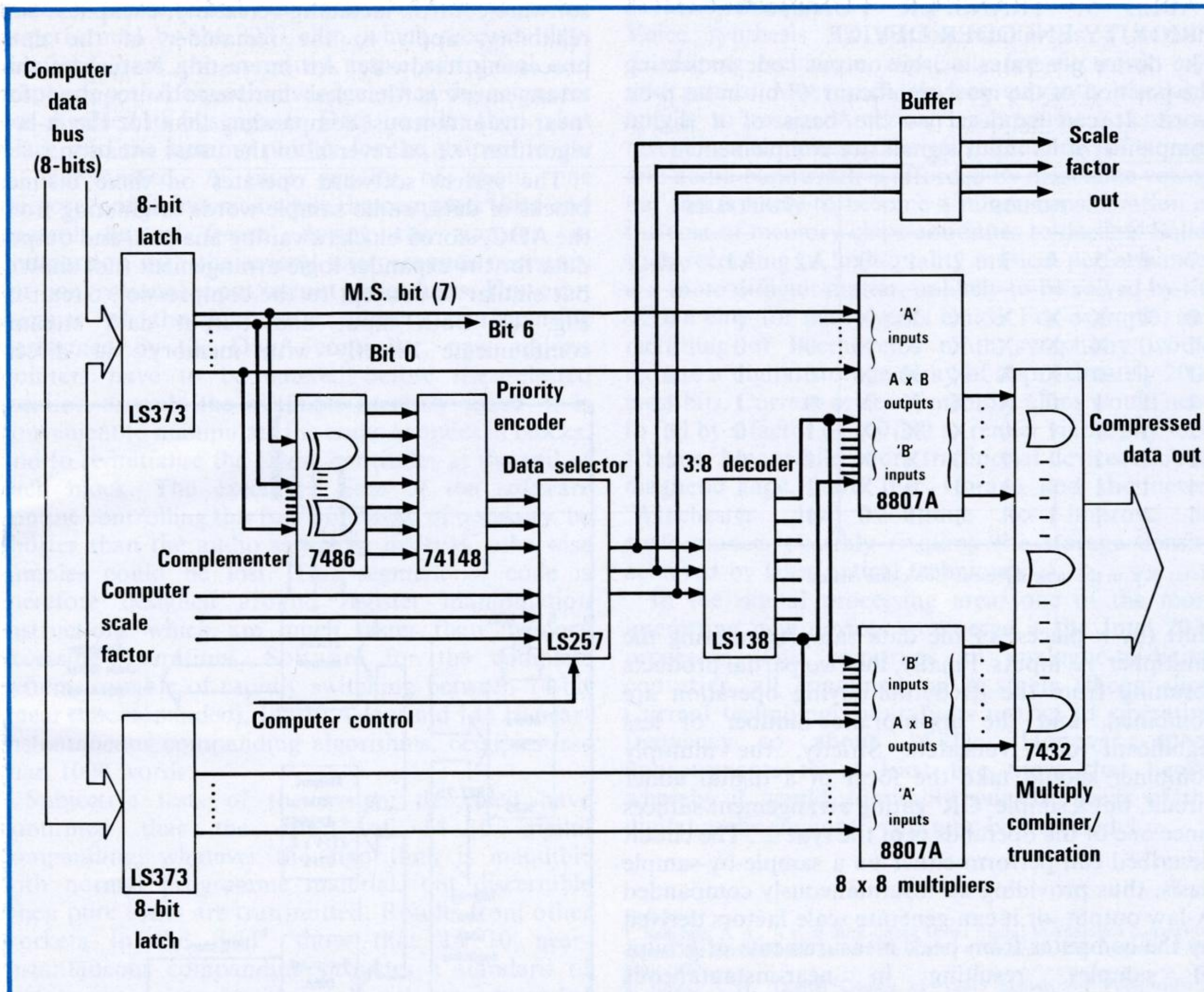


Fig. 1. Digital Audio Compression System. Compression is effected by shifting the digital samples left (towards the most significant bit) by an amount equal to the number of leading zeros in the data value. The 74148 priority encoder locates the position of the most significant '1' bit and produces a 3-bit code with is then decoded by the LS138 and applied to two 8 × 8 multiplier chips. These multipliers, together with the multiplier combiner, shift the input data word by the required amount.

Figure 1 illustrates a digital audio compression system used in the laboratories of the IBA to evaluate the performance of a variety of companding algorithms.

The system is designed as a peripheral interface to an 8-bit 8085 microcomputer, the 14-bit audio samples requiring two operations per processing step because of the 8-bit accumulator limitation. A priority encoder device (see Table 5) with complemented data inputs locates the position of the more significant '1' bits in the sampled data, and generates a 3-bit code related to the compression scale factor. Because the chosen ADC produces an 'offset binary' output, positive values require to be complemented before reaching the priority encoder. This is effected by applying the most significant bit to a set of exclusive 'OR' gates. Samples from a 'sign-plus-magnitude' converter would not require correction in this manner.

The audio samples are 'left-justified' to remove leading zeros by means of a multiplying technique. By decoding the scale factor in the 3 : 8-line decoder shown in Fig. 1, a digital number of the form 2^n is produced. This number is applied to the 'B' inputs of a pair of 8×8 parallel multiplier chips, causing a left-

TABLE 5: TRANSFER FUNCTION, 74148 PRIORITY ENCODER DEVICE

The device generates a 3-bit output code indicating the position of the most-significant '0' bit in an 8-bit word. It can be used as the basis of a digital compander if its input signals are complemented.

INPUTS								OUTPUTS		
7	6	5	4	3	2	1	0	A2	A1	A0
0	X	X	X	X	X	X	X	0	0	0
1	0	X	X	X	X	X	X	0	0	1
1	1	0	X	X	X	X	X	0	1	0
1	1	1	0	X	X	X	X	0	1	1
1	1	1	1	0	X	X	X	1	0	0
1	1	1	1	1	0	X	X	1	0	1
1	1	1	1	1	1	0	X	1	1	0
1	1	1	1	1	1	1	0	1	1	1

Note: 'X's' in the table represent 'don't care' states.

shift (by n places) of the data samples entering the multiplier 'A' inputs. Finally, the two partial products resulting from the 8×8 multiplying operation are combined, and the appropriate number of less significant bits truncated. Strictly, the multiply combiner should take the form of a digital adder circuit, but a simple 'OR' gating arrangement suffices since one of the operands is of the type 2^n. The circuit described can perform either on a sample-by-sample basis, thus providing an instantaneously companded A-law output, or it can generate scale factors derived by the computer from peak measurements of groups of samples, resulting in near-instantaneous companding.

Figure 2 shows the microprocessor configuration, based on the 8085 computer and standard memory and input/output devices. The interval between audio samples is 31·25 μs (32 kHz sampling), permitting a reasonable amount of signal processing on a per-sample basis, bearing in mind the 1·3 μs instruction cycle time of the 8085. For example, the peak value of a group of audio samples can be calculated by complementing negative values, 'OR-ing' each word with previous samples, and scanning the resultant value at the end of a cycle to determine the scale factor for the group. Insufficient processing power is available from the 8085 system to perform A-law companding by software, hence the derivation of 'instantaneous' scale factors by the 74148 priority encoder in Fig. 1. However, the usual benefits of software control, including versatility, cheapness and reliability, apply to the remainder of the data processing hardware. An interesting feature of this arrangement is that less hardware is required for 'near-instantaneous' companding than for the A-law algorithm; i.e., a reversal of the usual situation.

The system software operates on three distinct blocks of data, audio sample words originating from the ADC, stored blocks awaiting analysis, and output data for the expander logic arrangement (not shown, but similar in concept to the compression circuit of Fig. 1). Both input and output data streams communicate directly with memory via direct-

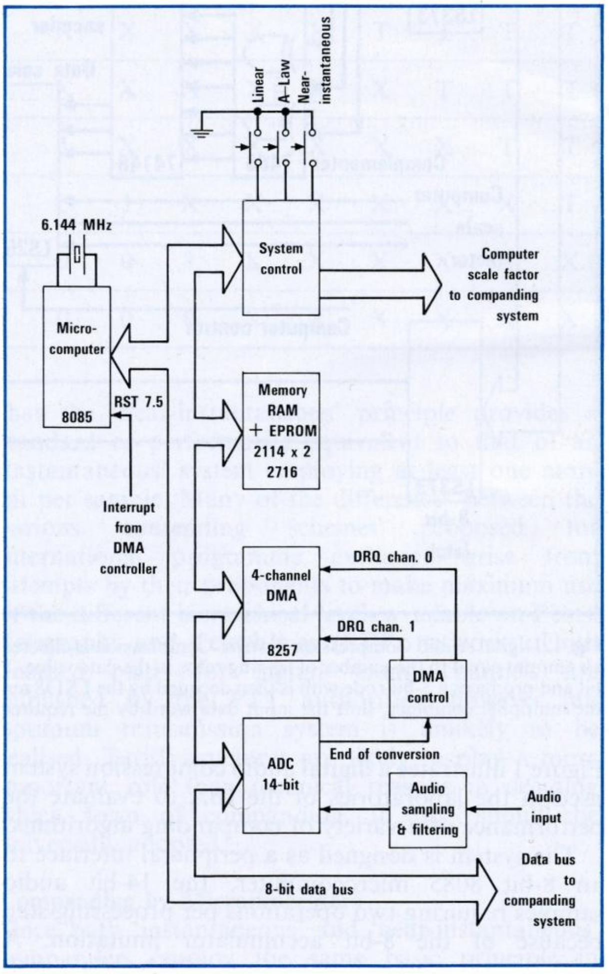


Fig. 2. Microprocessor System for Digital Audio Companding. Digital companding experiments can be undertaken with a relatively simple microprocessor system. The hardware configuration shown employs $1\,k \times 8$ RAM and $2\,k \times 8$ EPROM. 14-bit audio samples are processed as 8-bit word pairs.

memory-access (DMA) channels. DMA management is performed by the 8257 chip, which receives 'data requests' from the currently active peripheral and responds with 'data acknowledge' when the computer has disabled its bus signals. Data transfer then takes place, and the memory pointer for the channel in use is incremented. A time penalty of about one microsecond is incurred while the computer data and control busses 'freeze' during the transfer, in comparison with the several microseconds necessary for conventional input/output procedures. However, because of the automatic address incrementing performed by the DMA controller, new address pointers have to be entered before the selected location exceeds the available memory space. It is convenient to manipulate the audio samples in blocks, and to re-initialise the DMA controller at the end of each block. The execution time of the software routine controlling this function must, of necessity, be shorter than the audio sampling interval, otherwise samples could be lost. This segment of code is therefore designed around register manipulation instructions which are much faster than memory accessing operations. Software for the complete system, capable of rapidly switching between 14-bit linear (uncompanded), 14 : 10 A-law and 14 : 10 near-instantaneous companding algorithms, occupies less than 1000 words.

Subjective tests of the system described have confirmed that the effect of 14 : 10 digital companding, whatever the algorithm, is inaudible with normal programme material, but discernible when pure tones are transmitted. Results from other workers in the field[4] show that 14 : 10 near-instantaneous companding provides a standard of performance virtually identical with uncompanded sound. This is likely to be of great importance for satellite transmission, where significant savings in capital plant can be achieved if more channels can be accommodated within a given bandwidth.

Future Techniques

Voice synthesis by microcomputer is a rapidly developing technique, especially for electronic toys and games. Most such devices currently available appear to possess American or Japanese accents, so revealing their places of origin. Economy of storage and audio bandwidth is afforded by masculine voices, but this is likely to become a minor consideration as the cost of memory chips continues to decline. Solid-state recording of high-quality musical performances is a more difficult matter, unlikely to be solved by the silicon chip for many years hence. For example, any recording of Beethoven's ninth symphony would require a digital storage array of approximately 2000 megabits. Current prices of memory chips would need to fall by a factor of 100 000 to render viable any such scheme. Meanwhile, more traditional devices such as magnetic tape, hard disc storage and the newer 'Winchester disc' continue to improve in performance, possibly rivalling the storage density achieved by laser-optical techniques.

In the digital processing area, one of the more interesting new devices to emerge is the Intel 2920 processor. This comprises an analogue-to-digital converter, all contained on a single silicon slice. Current technology limitations restrict its operating frequency to about 14 kHz. However, speed improvements to at least five times that figure, whereby it would admirably suit the needs of the digital audio engineer, can now be expected.

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Enhanced Graphics for Teletext

by R H Vivian

ROY VIVIAN, BSc, CEng, MIEE, was educated at Dulwich College and the Universities of Reading and London. Since joining the E & D Department of the IBA in 1968 he has led projects to investigate the feasibility of off-air quality analysis of television signals by digital computer (the 'Lichfield Experiment') and to develop a colour VDU system for use in the Croydon Regional Operations Centre (ROC). At present he is concentrating on graphical enhancements (alpha-geometrics) for the UK Teletext system. He was previously with Elliott Automation, where he was responsible for the specification and development of pilots' head-up and head-down display systems. His earlier experience covered a wide field ranging from design of analogue and digital computers to high fidelity sound equipment, UHF and VHF mobile and fixed receivers. He has been involved with semiconductor applications since the very early days, having designed and built the first known British transistor radio receiver.

Synopsis

Now that many forms of UK teletext enhancement are being proposed, there is increasing interest in a compatible means of providing improved teletext graphics. Various approaches are possible; but, for diagrams, graphs, weather maps and simple animated cartoons, a system based on geometric primitives recommends itself as being conservative of transmitter teletext pages and suitable for ready inclusion in tele-software programs.

The cost of the necessarily enlarged receiver memory is liable to become less significant as a result of continually falling prices of semiconductors and offers good prospects of further reduction as a result of alternative storage techniques.

As in any system where all points on the screen may be randomly addressed, error protection assumes a role more important than that of the present day character-space related transmission format.

The transmission of still video quality pictures by teletext is discussed. Owing to the volume of data involved, this appears viable, in terms of a really satisfactory compromise between picture library and access time, only if the equivalent of many more television lines is made available for this purpose. This would result, for example, from the allocation of a full television bandwidth channel to data transmission, or the provision of an additional dedicated subcarrier in an existing television channel.

INTRODUCTION

The UK Broadcast Teletext specification[1] defines graphic modes in which certain of the available character codes are allocated to six-block 'mosaic' patterns, thereby providing a simple means of building up larger alphanumeric characters and various rough outline designs for display on the television screen ('alpha mosaics'). Two such graphic modes are specified; a 'contiguous' mode in which adjacent mosaic blocks are run together to form continuous areas of colour, and a 'separated' mode in which foreground elemental mosaic blocks are divided from one another by narrow strips of background colour.

These mosaic characters have proved a very useful

feature, as may be evidenced by their frequent occurrence in titles and broad brush pictures on the majority of current teletext magazine pages.

However, because of the inherent simplicity of these presentations, and the way in which both the mode and colour combinations are defined, they possess significant limitations which fall into three main categories:

1. The elemental blocks or 'pixels', each occupying 1/80 of the screen width and 1/72 of its height, allow only a coarse representation of lines and areas.
2. Only two previously defined colours can be employed in any single graphical character.
3. Additional control characters occupying character spaces on the screen are needed to define the mode and colour combinations of subsequent mosaic characters.

From the creative point of view, the last of these three is probably the most restrictive. For example, to change from red lower case alphanumeric characters on a black background to, say, blue-on-yellow graphical symbols requires three intervening control characters. In practice, the situation is somewhat alleviated by the ability to summon capital letters while in a graphics mode and by the use of the 'hold graphics' control character, which causes repetition of the last defined mosaic symbol within each of the control character spaces which would otherwise be displayed as blanks.

Many researchers are of opinion that increased flexibility and higher resolution would greatly enhance teletext graphics and that proposals to implement improvements of this kind must, while maintaining a high degree of compatibility with the existing specification, provide a means of displaying finer and smoother lines, and areas of flat colour, within boundaries more precisely defined. This would enhance the present UK teletext system as to include high resolution graphs, line drawings, coloured diagrams, maps and simple cartoons.

'Alpha geometric' extensions of this kind, implemented by means of 'picture description instructions' (PDI) are already incorporated in 'Telidon', an alternative data system proposed for use in Canada[2]. Thus, an improved British teletext graphics capability could be of great significance in gaining acceptance in countries which have not yet decided on an operational data broadcasting service. It could serve also towards raising the status of teletext among international standardisation committees.

Still-picture data broadcasting ('alpha photographics') is a further possible enhancement, the potential of which has been demonstrated experimentally on the Prestel service of British Telecom at 'Viewdata '80'. This type of extension might prove very attractive; for example, to advertisers; whereas, in practice, alpha geometrics might be of greater interest to educationalists.

The ability to mix all of these enhanced graphics capabilities, either within the current system or with an improved and compatible alpha mosaic data system, is highly desirable if the full potential of data broadcasting is to be achieved.

Alpha Geometrics

The upgrading of a teletext receiver to provide an improved graphics facility necessitates two hardware extensions: viz., intelligence in the form of a microprocessor to decode and implement the more complex instructions transmitted, and additional memory to store the more precisely defined images. For all except the simplest of alpha mosaic systems, present technology is unable to interpret directly (at the speed at which the screen is being scanned) between data efficiently encoded for transmission and the displayed picture. Several options are available. The simplest and least limited is that of providing one memory bit per primary colour (RGB) for each screen pixel, so that the screen is imaged as a series of pixel planes. A possible modification of this principle is of first dividing the screen area into character spaces (as for alpha mosaics) and then constructing the display from a sequence of character sized pixel planes randomly addressed to locations on the screen at scan time. For cases where a high proportion of character spaces contain no detail or are the same, this allows storage to be exchanged for complexity of addressing and updating; but, on increase of the number of character spaces which can be addressed, it approximates to the earlier case.

A further extension leads to a concept in which detail is confined to moveable groupings of pixels, known as 'sprites'. These can be moved randomly over the entire screen area and so exert a predetermined priority when overlapping occurs. The technique is especially useful for producing animated cartoons or pictures, but appears rather less well suited to the construction of graphs and larger geometric outlines.

A rather different approach to the problem is that of converting the geometric primitives into a sequence of change-of-state instructions (as in the first case described) but, instead of updating the individual

pixel stores, the instructions are, until scan time, stored in address and 'op' code form. These instructions must either be held in scan address order, or be sorted into such order prior to display. If the sorting is by row and by column, coincidence between the column address and horizontal scanning location can be identified by fast hardware, while the 'op' code is simultaneously interpreted as a colour or intensity change.

Alternatively, sorting into row order alone will suffice if each change of state instruction is decoded by software to update one (or more than one) line store just prior to scanning. However, a statistical limit on the maximum allowable number of changes for a line or group of lines is then imposed by the speed of the microprocessor employed.

The most economical method of encoding geometrical patterns for transmission is in what might be termed a 'geometric primitive format'. This requires specification of only the co-ordinates of the start and finish of a straight line, or centre and radius of a circle. Three points sufficiently define arcs of circles, while a sequence of co-ordinates may be used to indicate the vertices of a polygon. For shapes such as these, the link between received data and reconstructed image is software, which may either take the form of transmitted telesoftware or be implicit in the terminal as a stored fixed program ('firmware'). An additional algorithm may be added to allow bounded areas identified by a single location to be filled with a previously defined flat colour.

'Freehand', or non-geometrically constructed lines, need more elaborate specification, but can most simply be regarded as connected chains of picture elements or 'pixels' in which the incremental steps are confined to a maximum of eight directions (Fig. 1a). Extending the technique so as to define incremental runs of as many as two, or even four, successive pixels in the same direction might afford a possible improvement in transmission economy, on the assumption that the requisite lines are comparatively smooth (Fig. 1b).

It must, of course, still be possible to display alphanumeric characters when operating in an alpha geometric mode. These can be called up as superimposed normal teletext rows, or as character strings starting from any definable screen location (pixel), and so need not be restricted to the normal 24 teletext character rows. As these characters will be mapped from either a fixed character generator ROM or any other specified area of RAM storage, there is no additional problem in accommodating dynamically redefined character or symbol sets (DRCS) or in varying their sizes and aspect ratios, if required. Italics, rolling, and even proportional spacing, in which the widths of individual characters differ from one another and the inter-character spacings are varied to improve appearance and legibility, are equally feasible.

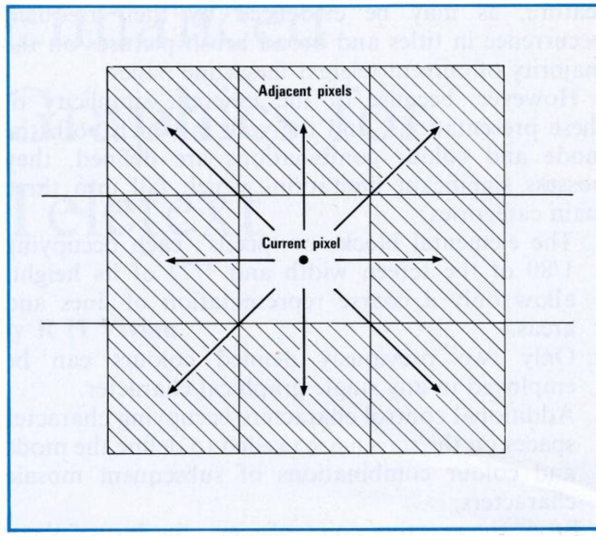

Fig. 1a. Consecutive pixels forming incremental sections of a continuous thin non-geometrical line must lie in one of eight directions from the current pixel.

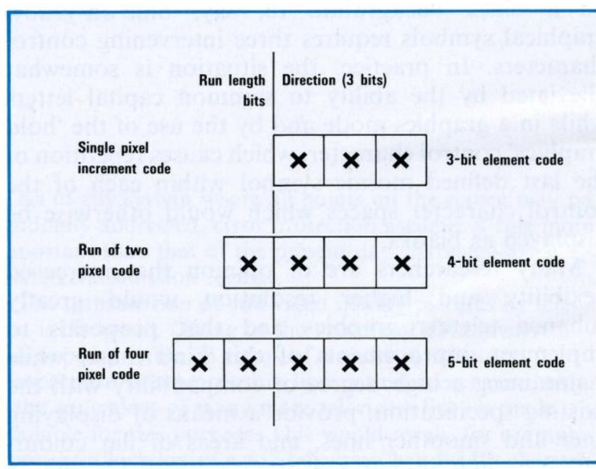

Fig. 1b. Code elements of non-geometric line formats may allow straight runs of 1, 2 or 4 pixels at a time in any of eight directions from the start or current pixel.

Error Protection and Recovery

The format of a current UK teletext page itself implies a high degree of error protection, supplemented by parity for the textual content and Hamming

protection for the addresses. As reception conditions deteriorate, errors first appear as missing characters (single or odd parity errors) or incorrect characters (double or even parity errors), all of which have an extremely high probability of correction on a second reception of the same page. Rarely are complete rows misplaced or overwritten by others from alternative pages, protection against such occurrence being afforded by the corrective properties of the Hamming coding.

In systems which have rows and columns randomly addressed (as, for example, in 'Antiope') improved flexibility is achieved at the greater risk of misplacing or incorrectly overwriting data. A similar problem occurs in an alpha geometric system where points are defined by their screen co-ordinates. Error protection therefore assumes greater significance, and further consideration must be given to prevention and recovery.

As a first step, the Hamming protection currently used for teletext addresses could be extended to the alpha geometric instruction (AGIs) and associated software, but the procedure is somewhat prodigal of protection bits, requiring a minimum of three to correct one error in four data bits. (Current teletext, in fact, employs four Hamming protection bits.) In the context of geometrically generated diagrams, it may be that error detection is of greater importance than the correction of single errors, when reception conditions produce multiple errors. The effects of undetected errors would, for example, be disastrous if a boundary were missing or misplaced when colour infill were called.

A cyclic redundancy check (CRC), whereby modulo addition of all bits in a data block produces a 'checksum' which is then transmitted together with the data, might afford better value here and can be applied to any quantity of data from a single AGI to a whole alpha geometric page.

Present day commercial decoders render both these suggestions difficult of putting into practice. This is because of the substituting of the space code '20' for the code received whenever a text error is detected.

Nevertheless, it is understood that many proposals currently being considered for various forms of teletext enhancement involve the use of the eighth bit other than for parity, so that it is confidently expected that, in future generations of teletext decoders, this substitution feature will be rendered optional.

Pixel and Memory Size

In a graphics system where all elements are specified as geometric primitives, the resolution or pixel size can ultimately be left to the discretion of the receiver manufacturer. If dynamically redefined characters and symbols are to be included in the system (unless these also are geometrically defined—which seems unlikely) some choice of standards has to be made at an early stage.

For the UK, the main constraints are the 625-line raster and the need of compatibility with the existing teletext system, in which a page of text comprises 24 rows of up to 40 alphanumeric characters. Allowing adequate margins, a full frame height of 575 interlaced video lines suggests a row height of ten line pairs, leading to a pixel height of one line pair.

If, therefore, the pixel is to approximate to a square element—which seems desirable if circles and arcs are to form part of the scheme—and each of the possible 40 characters forming a row is to occupy an integral number of pixels, then eight pixels per character space width would seem appropriate. Concerning character intelligibility, recent work reported from Germany suggests that an increase to 12 pixels per width would be advantageous.

In this context, a fundamental matrix of 240×320 pixels is preferred to the frequently suggested 256×256 or 512×512 matrix. The linear resolution could, of course, be doubled to specify fully each field independently; but this would quadruple the image memory required. Simultaneously, it would increase the number of teletext lines needed for transmitting dynamically redefined characters (16×20 pixels), freehand lines and co-ordinate locations.

The expected reductions in memory cost might encourage receiver manufacturers to employ the larger sized store in order to provide improved resolution. This increase in storage may in any case be necessary to accommodate other facilities such as 'alpha photographics'. There seems probability that techniques similar to the character rounding performed at scan time in most current teletext receivers will go a long way towards improving appearance without recourse to increased memory size.

The next question concerns the number of bits required by each pixel. This depends almost entirely on the editorial facilities to be provided. To display only the six saturated single intensity colours (plus black and white) forming the traditional colour bars requires only three bits, but this makes no provision for 'flashing' or the ability to distinguish alphanumeric characters when a subsequent colour infill is called. Additional bits could also be used to

vary luminance and to modify the selection of colours which could be drawn from a wide range, previously defined by special instructions for each individual page or page area. Four or five bits would thus appear minimal, leading to an image store of at least 38 k bytes, or some 40 k bytes when adequate dynamically redefined character and program storage are added. If some restriction in chromatic resolution is considered acceptable—again a choice open to the set designer—this could be reduced to 24, or even less, by using one bit per pixel for 'bright-up' while sharing the colour bits between a group of adjacent pixels. A more sophisticated scheme, affording a choice of luminous intensity together with a wider range of hue, would suggest one byte (8 bits) per pixel, increasing the image store to some 75 k bytes. Alternatively, the same size of memory might be organised as two separate image planes which could then be used for separate storage of 'foreground' and 'background' diagrams (see Fig. 3). In this way, by switching between the planes, special 'flashing' effects or some degree of animation could be introduced. For example, a simple line drawing could be updated in the background store while the foreground store was being displayed. The process would then be reversed and, by successive display cycles, would provide a means of synthesising continuous motion.

Alpha Photographics

Mention has already been made of the means by which full colour still pictures may be sent as teletext pages. The main parameters to be determined are the resolution and colour gradations considered acceptable to the viewer and, more importantly, whether a full frame picture of this sort is necessary. Current experiments suggest that a picture occupying perhaps only one-ninth of the screen area might suffice for many purposes. The key to the whole situation seems to lie in the coding technique employed.

A prime consideration is that of terminal storage because it represents the major contribution to additional receiver cost. The pixel size suggested earlier for alpha geometrics represents roughly half the linear resolution provided by 625-line PAL. Vertically, the pixels correspond to only the odd or even transmitted field. Horizontally, they represent roughly 140 ns interval samples.

In order to resemble the spatial resolution of a normal television picture, the number of pixels allocated to a corresponding area of alpha geometrics would therefore need to be trebled. As to the number of bits associated with each pixel, much depends on the colour coding philosophy. PAL or any other form of subcarrier coding does not appear especially relevant here, although there should still be the possibility of taking advantage of the lower chromatic acuity of the eye in order to optimise memory utilisation. For example, the colour components might be shared between small clusters of, say, four adjacent pixels (Fig. 2).

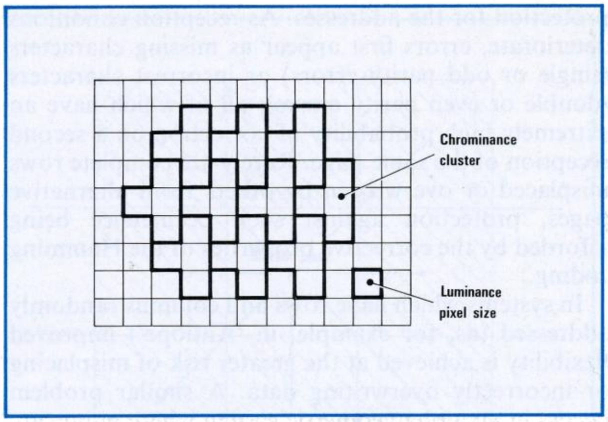

Fig. 2. Pixel Matrix indicates possible common chrominance clusters of 4 pixels.

On this basis, and allowing eight luminance bits per pixel plus an average of four chrominance bits, the 75 k bytes suggested for the alpha geometric mode, when suitably rearranged, would provide storage for a still picture of video-compatible quality covering approximately two-ninths of the screen area. However, a reduction to six luminance and two chrominance bits per pixel—using colour clusters of six—thereby increasing the available picture area to one-third that of the screen, might prove acceptable.

So far, no mention has been made of what can be displayed on the remaining part of the screen. The simplest solution would be to utilise the original page store to provide a reversion to the alpha mosaic teletext format currently used. Alternatively, a limited alpha geometrical facility could be retained with perhaps only a rudimentary colour capability. This would represent reduction of available picture size, to between one-eighth and one-fifth of the screen area, unless additional compensating memory were provided.

Picture Coding for Transmission

The amount of information contained in any picture of photographic quality is high. This necessitates optimising the coding employed for transmission such

as to reduce the number of teletext pages required. The problem is obviously related to that of storage, but there is considerable opportunity for re-encoding, provided that the conversion does not impose too heavy a burden on the terminal processor. The speed at which such a picture is built up on the screen is likely to be rather slow; hence, it is also desirable that the viewer shall, at an early stage, be able to gain sufficient appreciation of the picture content to decide whether or not to persevere to completion.

Perhaps the simplest efficient coding procedure so far suggested is of differential pulse code modulation (d.p.c.m.) which, with prediction, is generally accepted as producing a good compromise between picture quality and code reduction. Transform coding also has been suggested; suitable examples are Hadamard[3] and Slant[4] codings. The former appears easier to implement as it is based on a matrix consisting entirely of ± 1 and 0 terms which, for normal sized data blocks, can be expressed as the product of sparse matrices, leading to a simple hardware embodiment. However, from comparative trials[5] it is reported that its performance demonstrates little advantage, if any, over that of d.p.c.m.

Slant coding, according to its protagonists, affords some further improvement—possibly resulting from a more even sharing of the spectral energy among the sequency coefficients—but, because of the diverse values of the coefficients in the generating matrix, it appears more difficult of implementing.

As to early assessment by the viewer, with d.p.c.m. the picture is built up line by line. The time for recognition is therefore dependent on the point at which reception starts and on the picture content. On the other hand, Walsh-Hadamard coding starts by painting a broad brush block picture as a result of displaying information contained in the low order sequency coefficients, resolution thence improving as

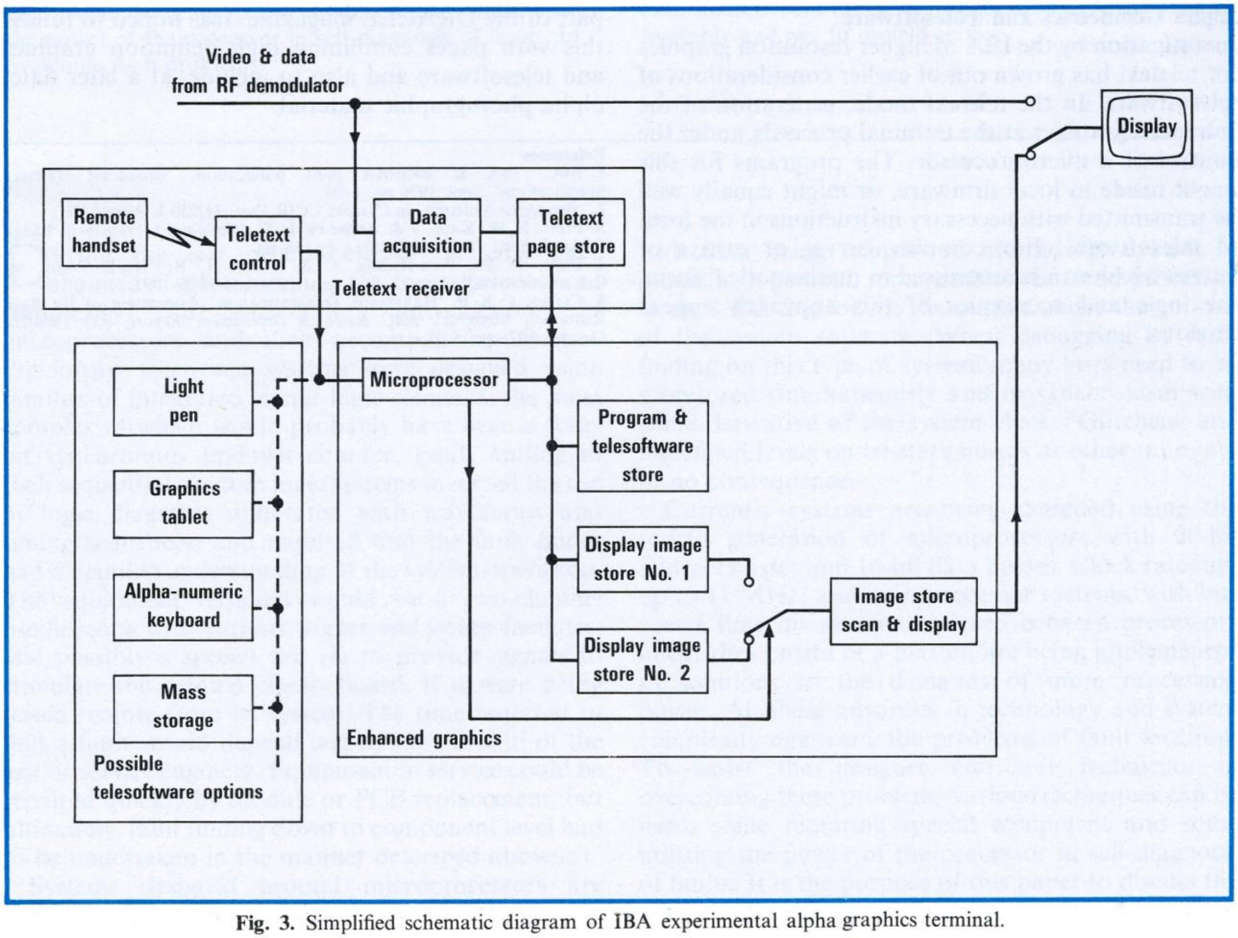

Fig. 3. Simplified schematic diagram of IBA experimental alpha graphics terminal.

successive coefficients are added. This assumes that reception commences at the lowest sequency coefficient, which is readily achieved by picture PRESTEL in which a picture is sent in response to a subscriber demand; but, in the case of transmitted teletext, the first coefficient received is entirely dependent on the current state of the sequence when a picture page is requested.

The problem might not be as serious as it first appears; because, as with the Fourier series (to which the underlying Walsh functions are analogous), there is complete correspondence between sequency coefficient order and frequency domain. Hence, it would seem that, if a mid-grey background is initially assumed, high order sequency coefficients should define sharp discontinuities such as outlines, and should consequently present to the viewer as much information as do the broad brush lower sequency coefficients.

Alpha Geometrics and Telesoftware

Investigation by the IBA of higher resolution graphics for teletext has grown out of earlier considerations of telesoftware. In the teletext mode, generation of the enhanced graphics at the terminal proceeds under the control of a microprocessor. The programs for this might reside in local firmware, or might equally well be transmitted with necessary instructions in the form of telesoftware. For complex curves or arrays of curves which can be expressed in mathematical form, the logic and economics of this approach appear obvious.

In the telesoftware mode a graphical representation of the results of calculations, for which some parameters would normally be supplied by the user, can, with advantage, be displayed by using the enhanced graphics capability. The simplified schematic diagram of the IBA experimental enhanced-graphics system, shown in Fig. 3, serves to illustrate the relationship which exists between alpha geometrics and telesoftware; the only significant additions to accommodate telesoftware being the optional input and output devices aimed at improving communication with the user. In this system the display store is organised as two image planes of 320×240 four-bit pixels; and the read-out is in groups of four as 16-bit words under the control of the Intel 8086 microprocessor.

An early experimental version of the IBA enhanced-graphics system was demonstrated on closed circuit, at IBC '80. Preparations are now well advanced for transmitting alpha geometric pages as part of the ORACLE magazine. It is hoped to follow this with pages combining high definition graphics and telesoftware and also to include, at a later date, alpha photographic material.

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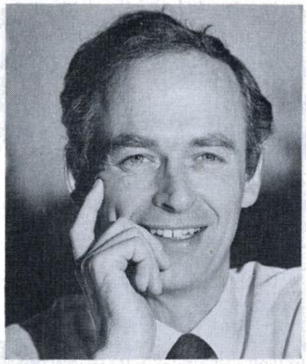


Techniques for Fault-finding in Microprocessor Based Systems

by S Day

Synopsis

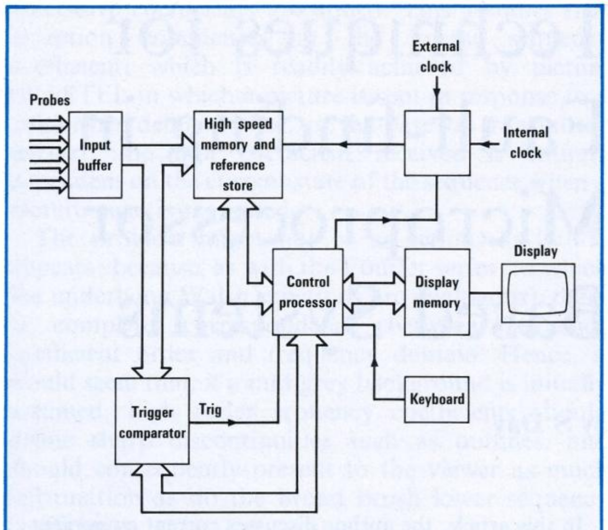
Advances in technology and system complexity aggravate the problems of fault location. Various techniques can be used, some requiring special equipment and others using the power of the processor in self-diagnosis of faults, to overcome such problems.

In this article, the author discusses current equipment and techniques. He indicates how they are applicable to fault finding from the design stage through development, assembly and test to in-field service.

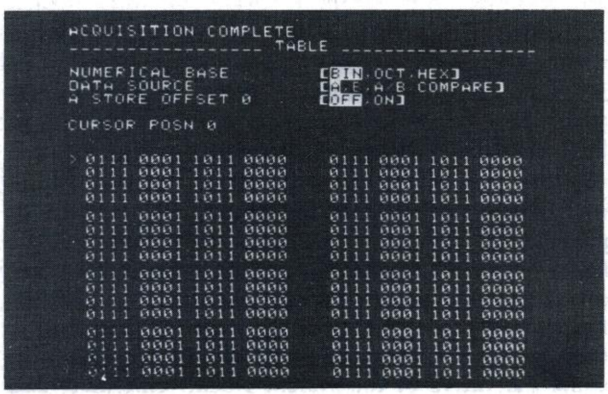
During the last decade electric systems have changed substantially in conception and complexity due to the introduction of microprocessors and their accompanying devices. Previously, electronic systems were designed using families of integrated circuit logic elements, the most complex of which would probably have been a four-bit synchronous updown counter. Fault finding in such sequential random logic systems involved the use of logic diagrams annotated with waveforms and timing sequences, and required that the fault finder had a detailed understanding of the system operation. The equipment required would be a two-channel oscilloscope with various trigger and sweep facilities, and possibly a special test rig to provide signals to stimulate the printed circuit board, if it were being tested remote from its system. The time required to find a fault would depend largely on the skill of the test or service engineer. Equipment in service could be repaired quickly by module or PCB replacement, but ultimately, fault finding down to component level had to be undertaken in the manner described above.

Systems designed around microprocessors are conceptually different in that they are bus structured with data being transferred around the system in parallel. In general, input data is read and processed in the CPU to produce the output under the control of the system software. When debugging or fault finding on this type of system, many lines need to be monitored simultaneously and in synchronism with some derivative of the system clock. 'Glitchers' and undefined levels on tri-state busses at other times are of no consequence.

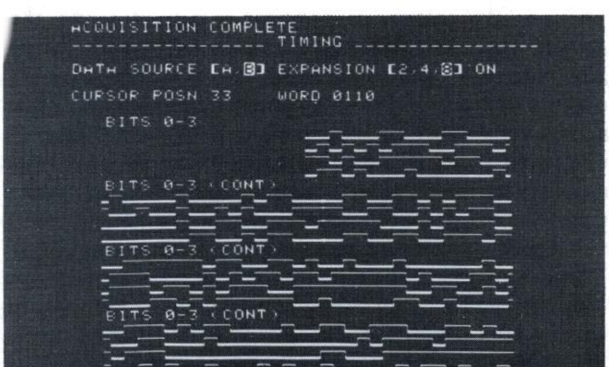
Currently systems are being designed using the fourth generation of microprocessors with 20-bit address busses and 16-bit data busses. Clock rates are up to 11 MHz; and multiprocessor systems, with bus access time division multiplexed between processors under the control of a master, are being implemented as solutions to the demands of more processing power. All these advances in technology and system complexity *aggravate* the problems of fault location. To assist the designer and test technician in overcoming these problems various techniques can be used, some requiring special equipment and some utilising the power of the processor in self-diagnosis of faults. It is the purpose of this paper to discuss the current state of the art equipment and techniques and



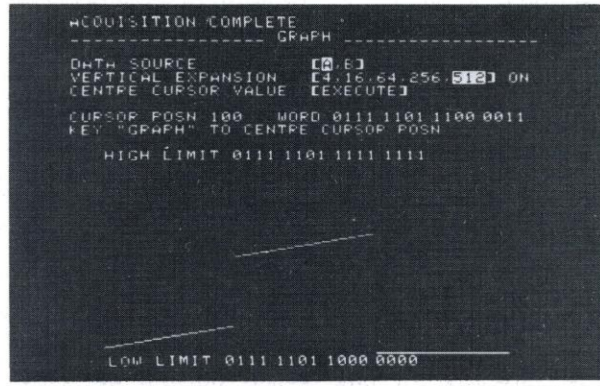
1 (a)
Logic analyser block diagram



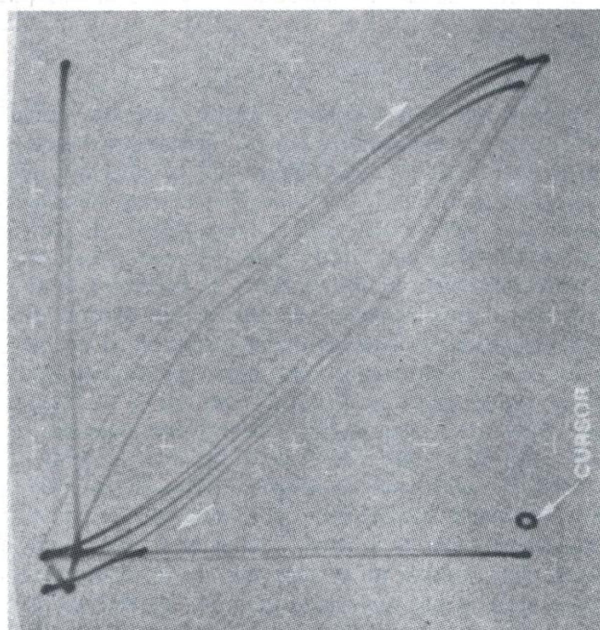
1(b)
Table



1(c)
Timing



1(d)
Graph



1(e)
Map

Fig. 1. **(a)** Logic Analyser Block Diagram; **(b)** Table; **(c)** Timing; **(d)** Graph; **(e)** Map.

indicate how they are applicable to fault finding from design and development through assembly and test to in-field service.

Logic Analysers

The logic analyser was the first of a range of equipments designed specifically for data domain analysis and was initially produced as an instrument for use in the laboratory during the development phase of a microprocessor implementation project. Its appearance was similar to an oscilloscope but having multiline data probes. The data on each probe line could be sampled under control of a system clock which could be qualified typically to sample once every processor instruction cycle. The samples were stored in an internal memory with a capacity of up to 16 × 16-bit words and the trigger word from which sampling was initiated was set up on a bank of switches.

More recently the ergonomics of logic analysers have been significantly improved and memory size has been increased up to 100 × 20-bit words. The options available for setting up the equipment are displayed as a menu on the screen, with a cursor to indicate the next input required. The keyboard is used to enter the information to give the required operating sequence. Typical of the options for trigger selection are: clock source, edge polarity, trigger work, clock cycles delay, trigger start or end, block pattern recognition etc. Possible data display modes on the screen are:

(*a*) Table. A listing of the sampled data states in binary or to some other numerical base such as hexadecimal (Fig. 1b).
(*b*) Timing. Data is displayed across the screen as several channels showing the H1–L0 activity (Fig. 1c).
(*c*) Graph. The address of each memory location is used as the X axis, while the Y axis is the numerical value of the contents of that address (Fig. 1d).
(*d*) Map. Each 16-bit sample is divided into its upper and lower 8-bit bytes. The lower byte produces the X axis deflection and the upper byte is the Y axis. The top left of the display is address 0000 and bottom right is FFFF. The map display will assume some unique pattern depending on the frequency of access of the various address locations being assessed by the program being created.

When monitoring the data on a microprocessor bus it is possible to re-convert the binary data back into its mnemonic assembly language form automatically and this feature known as disassembly has been built into some instruments. The analyser has a personality module according to the microprocessor in the system under development and the table display can then be a list of assembly language statements which are more readily interpreted for program debug.

Remote access for initialisation and interrogation can also be provided by connection to an instrumentation bus.

A further development of the logic state analyser is the logic tuning analyser. This device samples the data input lines with a clock which is asynchronous with the system under test. In this way it is possible to trap random events or 'glitches' as small as 5 ns wide by using clock frequencies up to 20 MHz. The display is usually presented as a timing diagram. One particularly useful application for this type of instrument is in trapping intermittent faults. The technique is known as 'babysitting'. Having established what trigger condition to use, a set of normal data is sampled and transferred to the secondary or referee memory. The user can now leave the instrument to monitor system under test and it will acquire new data each time the pre-selected trigger point is encountered. Any difference between the new data and the reference data will cause the analyser to stop sampling and indicate where the difference has occurred. On return the user can step through the logic timing diagram on the display and draw conclusions for further investigation of the fault.

In-circuit Emulation (ICE)

This is a technique for using a microprocessor development system to debug both hardware and software during the developmental phase of a project. Early microprocessor development systems were essentially for software development. They had the usual suite of routines for editing and assembling programs and it was possible to partially debug the software by limited execution within the development system. It was then necessary to commit the software to EPROM in order to transfer it to the hardware of the system being developed. For further debugging use was made of a logic analyser to find out why programs operated incorrectly or whether the fault was in the hardware.

Circuit emulation is created by additional hardware which allows the microprocessor in the target system to be emulated by a similar microprocessor in the development system. The ICE module connects to the target system by multi-umbilical cable terminated

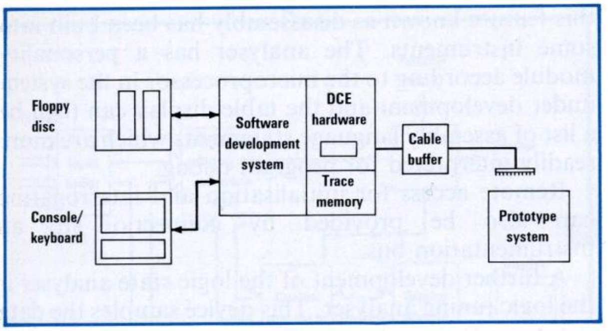


Fig. 2. In-circuit Emulation System.

with a plug which is inserted into the socket where the microprocessor would normally reside. In this way the resources of the development system are extended to the prototype in order to facilitate the hardware/software integration. Figure 2 shows a typical microprocessor development system with ICE. Resource allocation is extremely flexible in all modes of operation and will depend to some extent on the state of development of the prototype hardware. The development system mass storage medium, usually floppy disc, is used to store the target system software in both source and object form. Loading is quick and errors can be patched out in the object code to try modifications. These changes can then be incorporated in the source code and rapidly reassembled. Random access memory and I/O facilities of the development system can be used as though they are local memory and I/O of the prototype system even before this part of the hardware is built.

During emulation a breakpoint can be specified which can be conditional on a number of different factors such as memory read, memory write, instruction fetch or I/O operation at selected addresses. When the breakpoint has been encountered the internal registers of the processor and any memory locations can be interrogated and modified as necessary before re-starting emulation. It is also possible to display the contents of the trace memory to check the instruction sequence before the breakpoint.

Another possible mode of operation is Single Stepping. In this way more detailed information can be acquired by the trace memory as the program is executed one instruction at a time.

Probably the most important advantage of ICE is the simple connection into the prototype system. One cable is all that is required with no need for circuit modifications or temporary jumpers. Early development and debugging of the software enables completion of the total system integration in the shortest possible timescale. Finally, the time wasting procedure of needing to use EPROMS to transfer programs under development to the target system is eliminated.

Signature Analysis

If a piece of equipment is made to repetitively execute a certain sequence of instructions then it should be possible to identify correct operation by monitoring the changing logic levels at each node in the circuit. This would produce a mass of information which would be completely manageable in a test situation. In order to compress this information into a more useful form a technique known as signature analysis was developed by Hewlett Packard Ltd. The data appearing at a given node is sampled for a known period, between start and stop signals, by clocking it with the system clock into a feedback shift register. The residue at the end of the sampling period is characteristic of the activity at that node.

Using a 16-bit shift register and arranging the feedback such that a maximal length sequence is produced will give 65 536 possible residual states. The parallel 16-bit output from the register is used to drive four hexadecimal displays and the resulting number is termed the 'signature' of that node. Errors in the data stream will normally cause a different signature to be displayed. It is possible to show[1] that all single bit errors will change the signature and that the probability of multiple bit errors being missed is less than 0·002%. This is far better than the performance of other techniques such as bit or transition counting.

An example of how a signature is derived is shown in Fig. 3. The data signal is gated with the four feedback bits in a gate which produces only a logic one output when the modulo two sum of the inputs is one. The clock is enabled during the window between the start and stop pulses and in this case samples the data 20 times. The chart shows how the bits propagate through the shift register and the resulting signature is A682. Superimposed on the chart in red is the result of introducing a single bit error in the first bit. The signature changes to F3AA. In a similar way it could be shown that the signature would be 8E92 for an error in bit 8 and 2682 for an error in the last bit. Thus it can be seen that a single bit error even in such a short sequence will produce quite a dramatic change in the readout from the signature analyser. In a practical situation the window period would be considerably more than 20 clock periods and can be

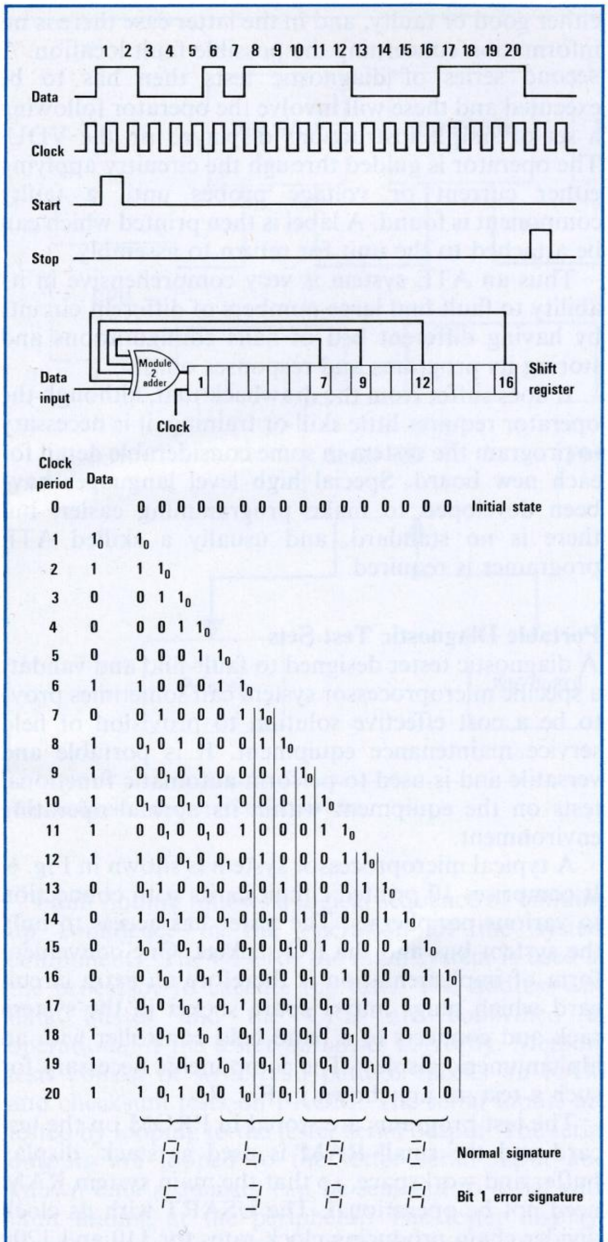


Fig. 3. Derivation of Signature from Data Stream.

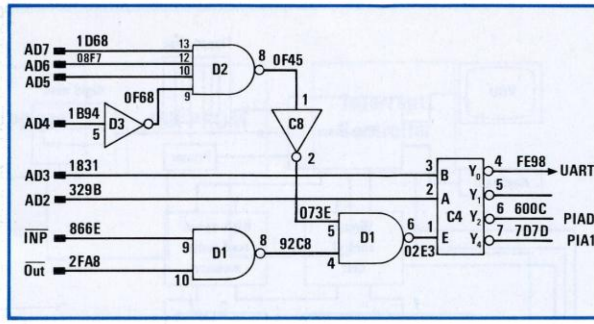


Fig. 4. Digital Circuit annotated with signatures.

more than 2^{16} (the cycle length of the register) if appropriate.

Signatures for a given circuit are not designed or calculated. What must be decided at the design stage is how start and stop signals can be produced and what hierarchy of tests is required to fully validate each node. This may involve the use of special test sockets to break feedback loops and violate parts of the circuit under test. Finally, when the design is complete, the test routines are executed and the signatures at each node in the equipment are recorded. Documentation is completed by adding the signatures to the circuit diagram an example of which is shown in Fig. 4. The handbook should detail the sequence of tests and fixtures, switches or jumpers that are required.

After proving the operation of the system kemel a series of tests are run which successively introduce a larger percentage of the system until a signature fault is found. Faulty components can be located by backtracking until a device with a correct input signature but erroneous output signature is found.

Signature analysis is a very powerful service aid and is also useful for final assembly testing. The equipment is relatively inexpensive and the extra design work is minimal. Retrospective design into existing systems is also an attractive proposition.

Automatic Test Equipment (ATE)

This is the name given to usually large equipment sets which allow the user to test, thoroughly and quickly, complex circuit boards. They represent a considerable capital investment and are essentially fixed. Usually they can be justified only in a production situation with a high throughput although sometimes there is a case for them in a repair and maintenance department.

A typical ATE system is shown diagrammatically in Fig. 5. User communication with the system is via the console keyboard and VDU. Test routines are stored either on floppy or rigid discs. The processor controls setting up and running of the tests. It communicates with the unit under test (UUT) via the digital control unit and the high speed read/write memory. Connection to the UUT is made in a

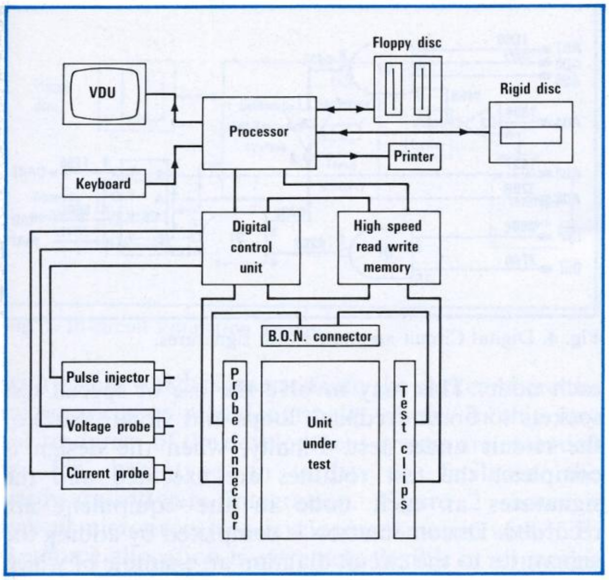


Fig. 5. ATE.

numbers of ways including via its edge connection, through a bed of nails fixture and through test clips and probes.

The usual test procedure involves the stimulation of the input nodes of the UUT with data in the form of arrays of sequential test patterns. The UUT is clocked at its normal operating speed and response data at all outputs and internal nodes is captured in the memory for comparison with the correct response pattern. Input sequences up to 4000 bits long are used and the output comparison is done either on a bit for bit basis or the response data is compressed into a signature for each node and then compared with stored signatures.

The input test patterns are usually algorithmically generated by the test procedure in order to simulate some functional response. Another possibility is to use pseudo-random binary sequences as input data providing a more exhaustive though lengthy test. The correct response patterns are assessed either by emulation or heuristically. In the first case it is necessary for the ATE to have detailed circuit information of the UUT and also to store a library of device models so that the correct response can be calculated. Functional models of complex LSI devices such as microprocessors are therefore required. In the second case a known good unit is monitored through all the tests and the correct responses are learnt and stored for later use.

The result of this initial testing is that the unit is either good or faulty, and in the latter case there is no information concerning the possible fault location. A second series of diagnostic tests then has to be executed and these will involve the operator following a set of simple instructions displayed on the VDU. The operator is guided through the circuitry applying either current or voltage probes until a faulty component is found. A label is then printed which can be attached to the unit for return to assembly.

Thus an ATE system is very comprehensive in its ability to fault find large numbers of different circuits by having different bed of nails configurations and storing its programs and responses on disc.

It does suffer from the drawback that, although the operator requires little skill or training, it is necessary to program the system in some considerable detail for each new board. Special high level languages have been developed to make programming easier, but there is no standard, and usually a skilled ATE programer is required.

Portable Diagnostic Test Sets

A diagnostic tester designed to fault-find and validate a specific microprocessor system can sometimes prove to be a cost effective solution to provision of field service maintenance equipment. It is portable and versatile and is used to perform automatic functional tests on the equipment within its normal operating environment.

A typical microprocessor system is shown in Fig. 6. It comprises 10 printed circuit cards with connection to various peripherals. The tester has access to only the system bus and the I/O sockets. One convenient form of implementation is therefore an extra circuit card which plugs into a spare socket in the system rack and connects to a hand held controller with an alphanumeric display. The components necessary for such a test set are shown in Fig. 7.

The test programs are stored in PROM on the test card and the small RAM is used as stack, display buffer and workspace, so that the main system RAM need not be operational. The USART with its clock divider chain producing clock rates for 110 and 1200 baud is used to test the serial links. One PIA controls the display and reads the keypad and the other is used to test the interrupt system and the parallel I/O. The most convenient address at which to locate the test routines will normally be zero so that system reset will initiate the test sequence. It will probably therefore be necessary to have a switch system which will disable memory at overlagging addresses while the test routines are executing.

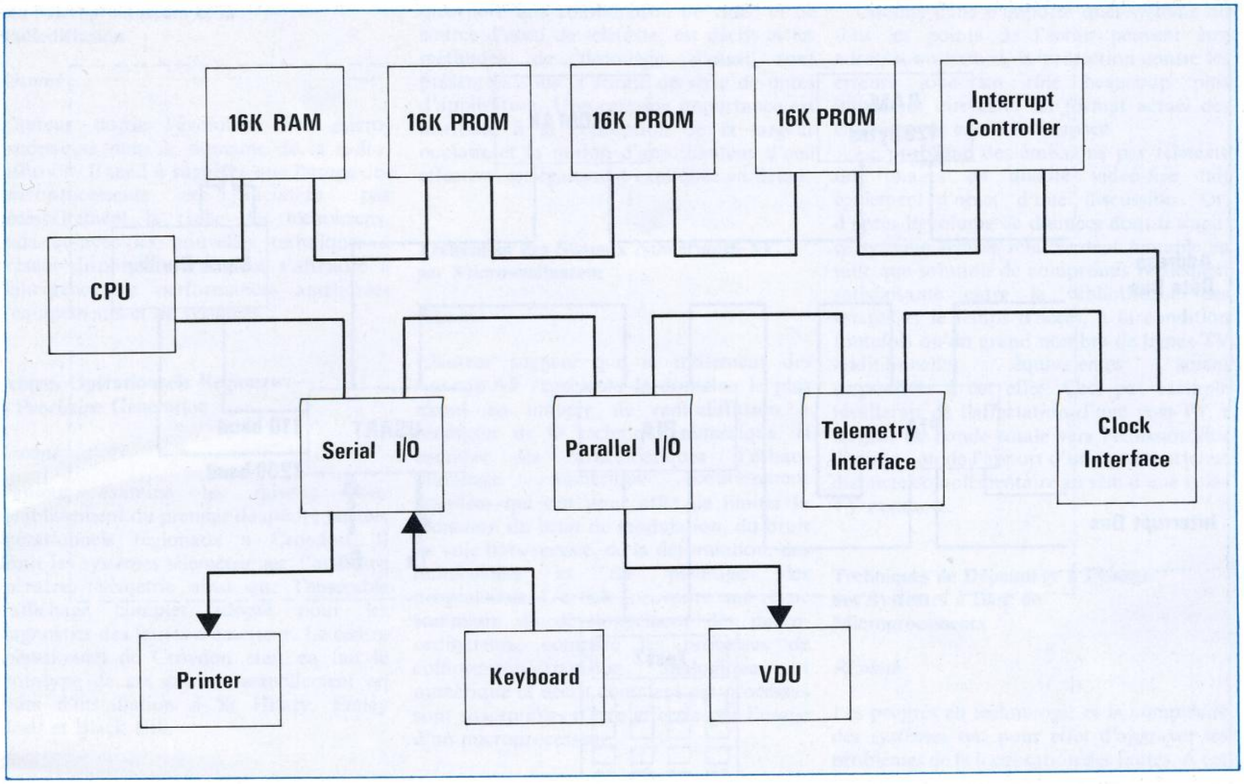


Fig. 6. Typical microprocessor system.

Fault finding follows a logical sequence of building up confidence in the operation of the system components. The CPU of the main system is used as the processor to execute the tests. The address and data busses and the CPU are confirmed as operational if the tester initialises correctly. Memory tests consist of write-read pattern checks on RAM and checksum tests on PROM. The serial inputs are tested by looping to the tester serial output. The serial outputs are looped to the tester serial input and known data sequences can be sent out to assist with fault finding at the peripheral. The tester displays diagnostics for each test to indicate success or failure of the mode. In the case of PROMS and RAMS the actual faulty chip can be indicated. The fault, when located, can be rectified by changing a circuit card; or a series of lower level tests can be executed in order to fault-find down to component level with the aid of scope and logic analyser.

In many systems validation routines are an integral part of the software and are run at initialisation. However, they cannot perform such comprehensive tests as this type of portable test set with interaction of a maintenance engineer. The operation of the tester is straightforward and requires minimum documentation. It is also readily acceptable as part of the maintenance engineer's kit.

Conclusions

Several techniques have been discussed in this paper which make fault analysis in the data domain a practical proposition. In a design and development laboratory, use is made of logic analysers and microprocessor development systems with in circuit emulation. In production and field maintenance the choice is less straightforward. ATE for assembly use appears to be the best technique for thorough testing but is costly both in initial equipment and in programming. Equipment for service use can be selected only when a maintenance philosophy has been evolved depending on the type of equipment, numbers in service, ability and availability of field personnel, acceptable down time etc.

Future developments will see the introduction of 32

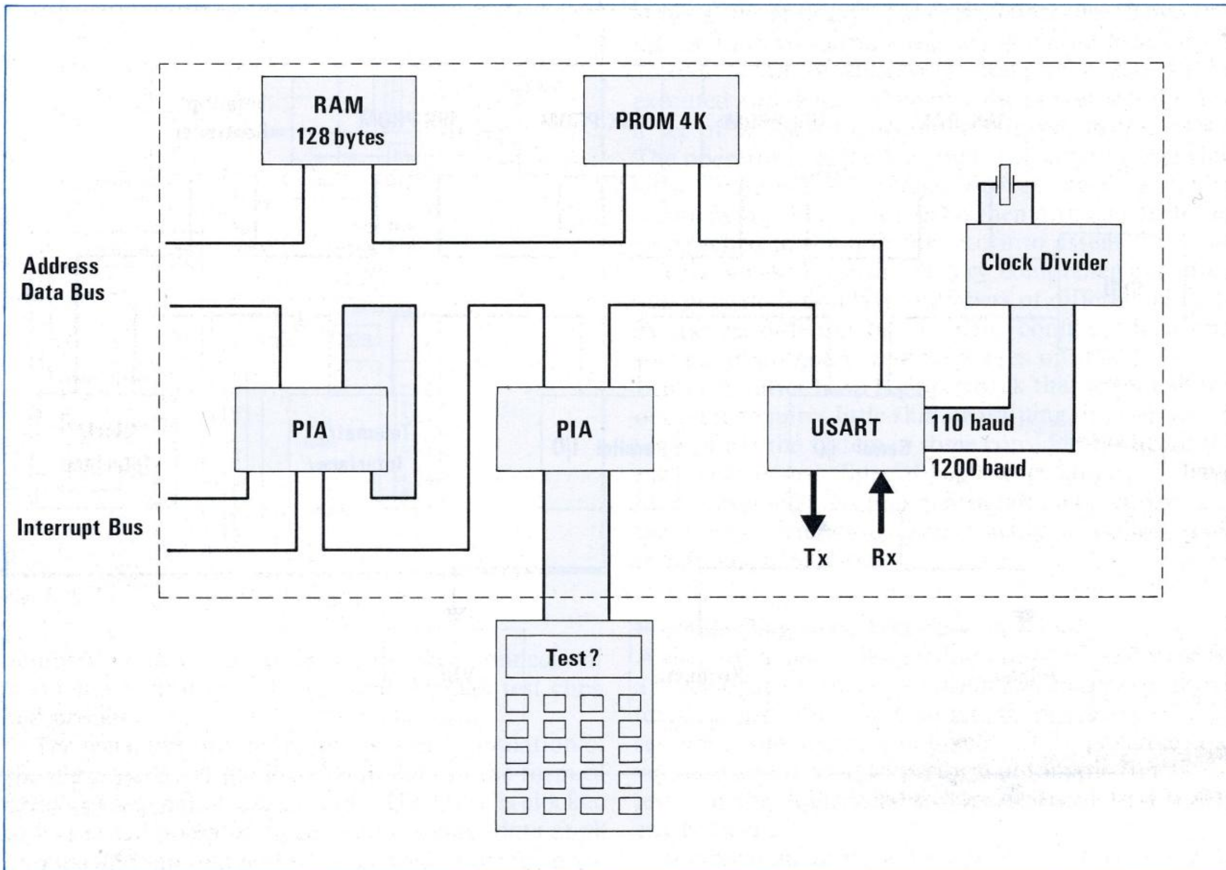


Fig. 7. Test set comprising PCB and control module.

and 64-bit microprocessor systems which will require even more sophisticated techniques for fault finding. Designs will become fault tolerant by the introduction of both chip and peripheral hardware redundancy. In the field there will be greater use of remote fault analysis. Faulty systems will be connected by telephone lines to central installations, the test routines being down loaded and results fed back for analysis.

There will therefore be a continuing trend towards improved system reliability by increasing MTBF and minimising down time on the occurrence of a fault.

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1. Frohwerk, R A, 'Signature analysis: a new digital field service method'. HP Journal, May 1977.

Les Microprocesseurs et la Radiodiffusion

Résumé

L'auteur décrit l'évolution des microprocesseurs dans le domaine de la radiodiffusion. Il tend à suggérer que l'usage des microprocesseurs ne facilitera pas nécessairement la tâche des techniciens, mais qu'avec les nouvelles techniques à présent disponibles, on peut s'attendre à l'émergence de performances améliorées d'équipements et de systèmes.

Centres Opérationnels Régionaux—la Prochaine Génération

Résumé

L'auteur examine les raisons pour l'établissement du premier de quatre centres opérationnels régionaux à Croydon. Il décrit les systèmes télémétriques, l'interface opérateur/télémétrie ainsi que l'ensemble d'affichage complet adopté pour les diagnostics des fautes d'émetteur. Le centre opérationnel de Croydon était en fait le prototype de ces centres actuellement en cours d'installation à St Hilary, Emley Moor et Black Hill.

Générateur der Mire Electronique

Résumé

Le générateur de mire électronique a été mis au point pour remplacer les dispositifs de balayage à curseur qui produisent la carte d'essai du type 'F' aux points d'entrée de programme dans le réseau de la Télévision Indépendante. Il s'agit en effet d'une unité compacte et fiable qui ne nécessite pour ainsi dire aucun entretien et qui utilise certaines techniques numériques pour générer le signal à partir de données de mémoire permanente.

La mire comporte de nombreuses caractéristiques spécialement conçues pour aider le réglage des récepteurs-TV de couleur ou monochromes et celle-ci est transmise tous les jours avant le commencement des programmes.

Systéme 'Delphi'

Résumé

L'auteur décrit un équipement de décodage d'essai et une norme de laboratoire à hauteur d'oeil désignés sous le nom de 'Delphi'. Le rôle de cet équipement qui incorpore une combinaison de vidéo et de source d'essai de télétexte, est décrit et les méthodes de décodage d'essai sont présentées sous la forme de série de notes d'application. Une certaine importance est attribuée à la conception de la largeur oculaire et la notion d'une 'hauteur d'oeil effective' est également expliquée en détail.

Traitement des Signaux Numériques-AF par Micro-ordinateur

Résumé

L'auteur suggère que le traitement des signaux-AF représente le domaine le plus récent en matière de radiodiffusion à bénéficier de la technique numérique. Il énumère les caractéristiques d'échantillonnage numérique couramment adoptées qui ont pour effet de limiter la réduction du bruit de modulation, du bruit de voie hors-service, de la déformation, des hululements et du pleurage des programmes. L'article incorpore une revue sommaire du développement des micro-ordinateurs, compare les processus de compression/expansion analogique et numérique et décrit comment ces processus sont susceptibles d'être affectés par l'usage d'un microprocesseur.

Présentations Graphiques Améliorées à l'Usage des Télétextes

Résumé

Etant donné qu'à présent de nombreux formats sont proposés pour l'amélioration des télétextes du Royaume-Uni, il subsiste un intérêt sans cesse croissant à trouver une méthode compatible permettant de produire des présentations graphiques de télétextes améliorées. A cet égard, diverses approches sont possibles, mais en ce qui concerne les diagrammes schématiques, les courbes, les cartes météorologiques et même les simples dessins animés, on tend à recommander un système basé sur des éléments géométriques primaires représentant une disposition conservatrice des pages d'émission télétexte et suffisamment adéquats pour l'insertion immédiate dans les programmes de télé-software.

Le coût de la mémoire du récepteur nécessairement agrandie est susceptible de devenir moins significatif par suite de la baisse constante du prix des semi-conducteurs et de plus présente d'excellentes perspectives de réductions complémentaires grâce aux techniques de stockage alternatives.

Comme dans n'importe quel système où tous les points de l'écran peuvent être adressés au hasard, la protection contre les erreurs joue un rôle beaucoup plus important que celui du format actuel des émissions de caractères/espace.

Le problème des émissions par télétexte des images de qualité vidéo-fixe fait également l'objet d'une discussion. Or, d'après le volume de données dont il s'agit, ce système semble relativement rentable en tant que solution de compromis réellement satisfaisante entre la bibliothèque des images et le temps d'accès, à la condition toutefois qu'un grand nombre de lignes-TV additionnelles équivalentes soient disponibles à cet effet. Ceci par exemple résulterait de l'affectation d'une voie-TV à largeur de bande totale vers l'émission des données, ou de l'apport d'une sous-porteuse distincte complémentaire au sein d'une voie-TV existante.

Techniques de Dépannage à l'Usage des Systémes à Base de Microprocesseurs

Résumé

Les progrès en technologie et la complexité des systèmes ont pour effet d'aggraver les problèmes de la localisation des fautes. A cet égard, il est possible d'utiliser différentes techniques dont certaines nécessitent des équipements spéciaux et d'autres qui emploient la puissance du processeur pour l'auto-diagnostic des pannes.

Dans cet article, l'auteur examine les équipements et techniques couramment en usage. Il montre comment ils peuvent être appliqués aux opérations de dépannage depuis le stade de la conception jusqu'au service en campagne, par l'intermédiaire du développement, du montage et des essais.

Mikroprozessoren im Rundfunkwesen

Übersicht

Der Verfasser beschreibt die Entwicklung von Mikroprozessoren auf dem Gebiet des Rundfunkwesens. Er vertritt die Ansicht, daß der Einsatz von Mikroprozessoren keine Erleichterung für den Techniker bedeutet, sondern daß aufgrund der neuen jetzt zur Verfügung stehenden Verfahren von Geräten und Systemen eine erhöhte Leistung erwartet wird.

Regionale Operationszentren—die Nächste Generation

Übersicht

Der Verfasser bespricht die Gründe, die zur Einrichtung des ersten von vier Operationszentren in Croydon führten. Er beschreibt die Telemetrie-Systeme, die Wechselbeziehung Bedienender/Telemetrie und das für die Sendefehler-Diagnose benutzte umfangreiche Displaygerät. Das ROC in Croydon war der Prototyp für die anderen Zentren, die jetzt in St. Hilary, Emley Moor und Black Hill eingerichtet werden.

Der Elektronische Testbildgenerator

Übersicht

Der elektronische Testbildgenerator wurde als Ersatz für Gleitabtaster entwickelt, die an Programminjektionspunkten im unabhängigen Fernsehnetz Prüfkarte F vorzeigen. Es handelt sich um ein kompaktes und zuverlässiges Gerät, das praktisch wartungsfrei ist und Digitalverfahren zur Erzeugung des Signales verwendet, wobei in Festspeichern enthaltene Daten zum Einsatz kommen.

Das Testbild mit seinen vielen Merkmalen wird zur Einrichtung von Farb- und Schwarzweiß-Empfängern benutzt und wird täglich vor Programmbeginn gesendet.

DELPHI

Übersicht

Der Verfasser beschreibt ein Dekodiertestgerät mit Laboraugenhöhe-Ständer, genannt 'Delphi'. Erläutert wird die Arbeitsweise des eine kombinierte Video- und Bildschirmtext-Prüfquelle darstellenden Gerätes sowie die Dekodierprüfmethoden, die anhand einer Reihe von Anwendungshinweisen beschrieben werden. Die Bedeutung der Augenbreite wird unterstrichen, ferner wird der Begriff einer 'effektiven Augenhöhe' erklärt.

Digitale Niederfrequenz-Signalverarbeitung durch Mikrocomputer

Übersicht

Nach Ansicht des Verfassers ist im Rundfunkwesen die Niederfrequenz-Signalverarbeitung das neueste Gebiet, dem die Digital-Technologie zugute kommt. Er führt die gegenwärtig akzeptierten digitalen Abtastcharakteristiken auf, die die Reduzierung von Programm-Modulationsgeräuschen, Freikanalgeräuschen, Verzerrung und Tonhöhenschwankungen durch ungleichmäßigen Bandlauf begrenzen. Der Artikel enthält einen kurzen Überblick über die Entwicklung des Mikrocomputers, vergleicht analoge und digitale Dynamikregelung und beschreibt den Einfluß, den der Einsatz eines Mikroprozessors auf die Dynamikregelung hat.

Verbesserte Grafik für Bildschirmtexte

Übersicht

Jetzt da mancherlei Vorschläge zur Verbesserung britischer Bildschirmtexte eingehen, besteht zunehmendes Interesse an einem verträglichen Mittel zur Erzeugung einer verbesserten Bildschirmtext-Grafik. Verschiedene Möglichkeiten bieten sich an, jedoch empfehlt sich für Diagramme, Schaubilder, Wetterkarten und einfache Zeichentrickfilme ein auf geometrischen Originalformen basierendes System, das sparsam mit den Bildschirmseiten des Senders umgeht und sich ohne weiteres in Ferhseh-Softwareprogramme einbeziehen läßt.

Die Kosten für einen notwendigerweise größeren Empfangsspeicher verlieren an Bedeutung im Hinblick auf die ständig sinkenden Preise für Halbleiter, und ein weiterer Kostenrückgang ist aufgrund neuer Lagerungsverfahren zu erwarten.

Wie in jedem System, bei dem alle Punkte auf dem Bildschirm nach Belieben angesprochen werden können, spielt die Absicherung gegen Fehler jetzt eine wichtigere Rolle als das gegenwärtige Kennzeichen/Zwischenraum-bezogene Sendeformat.

Besprochen wird auch die Übertragung von Standbildern mit Videoqualität durch Bildschirmtext. Wegen der großen Datenmenge ist dies im Sinne eines rundum zufriedenstellenden Kompromisses zwischen Bildbibliothek und Zugriffszeit nur dann möglich, wenn zu diesem Zweck das Äquivalent vieler weiterer Fernsehleitungen zur Verfügung gestellt wird. Dies ergäbe sich zum Beispiel, wenn der Datenübertragung ein Kanal mit voller Fernsehbandbreite zuerteilt würde, oder wenn in einem bestehenden Fernsehkanal ein zusätzlicher Spezial-Hilfsträger vorgesehen würde.

Verfahren zur Fehlerfeststellung bei Systemen auf Mikroprozessorbasis

Übersicht

Fortschritte in der Technologie und System-Komplexität erschweren die Problem der Fehlerfeststellung. Verschiedene Verfahren kommen hierfür in Betracht; für einige sind Spezialgeräte erforderlich, andere machen sich bei der Selbstdiagnose von Fehlern die Leistung des Prozessors zu Nutze, um derartige Probleme zu bewältigen.

In diesem Artikel bespricht der Verfasser gegenwärtige Geräte und Verfahren. Er führt aus, wie sich hiermit in jedem Stadium, von der Planung über die Entwicklung und Montage bis hin zur Prüfung im Einsatz Fehler feststellen lassen.

Los Microprocesadores en Radiodifusion

Resumen

El autor describe la evolución de los microprocesadores en el campo de la radiodifusión. Afirma que el empleo de microprocesadores no simplificará el trabajo de los ingenieros, pero que, con las nuevas técnicas de que actualmente se dispone, se espera un aumento de los rendimientos de equipos y sistemas.

Centros de Operaciones Regionales—la Proxima Generación

Resumen

El autor revisa los motivos para establecer el primero de los cuatro Centros de Operaciones Regionales en Croydon. Describe los sistemas de telemetria, la interfaz de operador/telemetría y la unidad de presentación visual extensa empleada para diagnosticar averías del transmisor. El C.O.R. de Croydon fue el prototipo de los C.O.R. que están siendo instalados actualmente en St. Hilary, Emley Moor y Black Hill.

Generador de Patrón de Pruebas Electrónico

Resumen

El generador de patrón de pruebas electrónico ha sido desarrollado para sustituir los exploradores deslizantes que producen la Tarjeta de Pruebas F en puntos de inyección de programa de la red de Televisión Independiente. Es una unidad fiable y compacta, que no requiere prácticamente mantenimiento alguno, y emplea técnicas digitales para generar las señales de datos mantenidos en memorias de lectura solo.

El patrón de pruebas tiene muchas características diseñadas para facilitar la puesta a punto de televisores en color y monocromáticos, y se transmite diariamente antes del comienzo de los programas.

DELPHI

Resumen

El autor describe un equipo de prueba decodificador y estándar de laboratorio de altura de vista denominado 'Delphi'. Se describe la función del equipo, una fuente de prueba de teletexto y video combinado, dándose métodos de prueba de decodificador en un conjunto de notas de aplicación. Se destaca la importancia de la anchura de vista y se explica el concepto de una "altura de vista efectiva".

Proceso de Señales de Audio Digitales por Microcomputador

Resumen

El autor señala que el proceso de señales de audiofrecuencia es una de las más recientes esferas de la radiodifusión que se beneficia de la tecnología digital. Relaciona las características de muestreo digital aceptadas generalmente que limitan la reducción del ruido de modulación de programa, del ruido del canal fondo, de la distorsión y gimoteo y titilación. El artículo incluye una breve revista al desarrollo de microcomputadores, compara la compansión analógica y digital y describe cómo es afectada la compansión por el uso de un microprocesador.

Gráficos Intensificados para Teletext

Resumen

Ahora que se están proponiendo muchas formas de intensificación de teletext UK (transmisión de información impresa), existe un creciente interés en un medio compatible para ofrecer gráficos de teletext mejorados. Son posibles varios enfoques; pero, para diagramas, gráficos, mapas meteorológicos y dibujos animados sencillos, se recomienda un sistema basado en principios geométricos por conservar páginas de teletext del transmisor y ser adecuado para inclusión inmediata en programas de telesoftware.

El coste de la memoria receptora necesariamente aumentado, tenderá a ser menos importante como resultado de la caída continua de los precios de los semiconductores y ofrece buenas perspectivas de reducción ulterior como resultado de las técnicas de almacenamiento alternativas.

Como en todo sistema en que todos los puntos en la pantalla sean direccionables aleatoriamente, la protección de error asume un papel más importante que el actual formato de transmisión de relación carácter-espacio.

Se discute la transmisión de imágenes fijas de video de calidad por teletext. Debido al volumen de los datos incluidos, esto aparece factible, en términos de un compromiso realmente satisfactorio entre bibilioteca de imágenes y tiempo de acceso, únicamente si se dispone para este fin de muchas más líneas de televisión. Esto se conseguiría, por ejemplo, mediante la dedicación de un canal de banda de televisión complets para la transmisión de datos, o la provisión de una subportadora dedicada adicional en un canal de televisión existente.

Técnicas para Localización de Averias en Sistemas Basados en Microprocesador

Resumen

Los avances en tecnología y la mayor complejidad de los sistemas agravan los problemas de localización de averías. Pueden emplearse diversas técnicas, requiriendo algunas equipo especial y usando otras la potencia del procesador para el autodiagnóstico de averías, para vencer dichos problemas.

En este artículo, el autor discute el equipo y las técnicas actuales. Senala cómo se aplican a la localización de averías desde la etapa de diseño a través del desarrollo, montaje y prueba hasta el servicio en el campo.

IBA TECHNICAL REVIEW

1 **Measurement and Control***

2 **Technical Reference Book, edition 3***

3 **Digital Television***

4 **Television Transmitting Stations***

5 **Independent Local Radio***

6 **Transmitter Operation and Maintenance***

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